(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 July 2004 (29.07.2004)

PCT

(10) International Publication Number
WO 2004/063090 A2

(51) International Patent Classification[7]: B81B

(21) International Application Number: PCT/US2004/000667

(22) International Filing Date: 12 January 2004 (12.01.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/439,768 13 January 2003 (13.01.2003) US

(71) Applicant (*for all designated States except US*): **TRIAD SENSORS INC.** [US/US]; 2700 Black Oaks Lane North, Minneapolis, MN 55447 (US).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **SCHILLER, Peter J.** [US/US]; 12370 Heather St. NW, Coon Rapids, MN 55433 (US).

(74) Agents: **XU, Min S. (Amy)** et al.; Dorsey & Whitney LLP, 50 South Sixth Street, Suite 1500, Minneapolis, MN 55402-1498 (US).

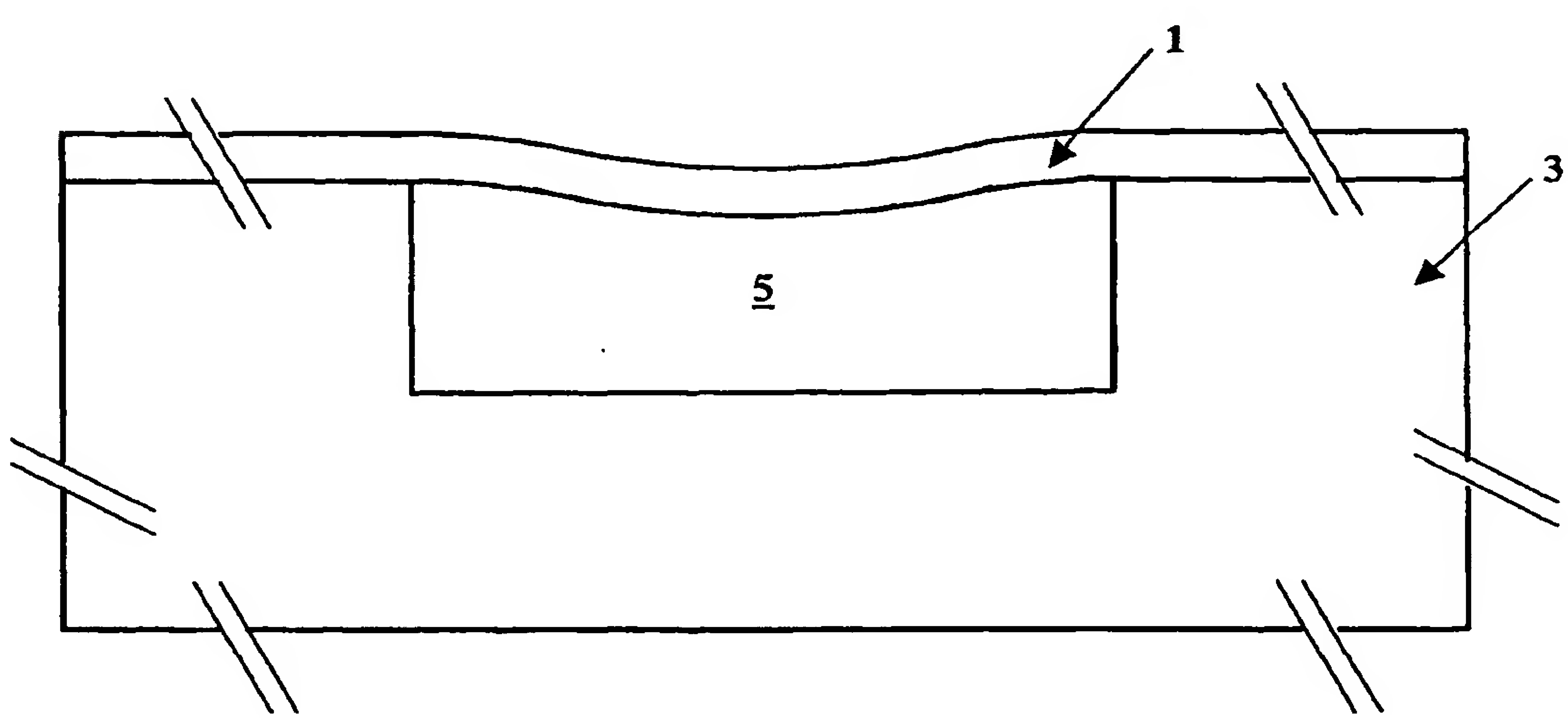
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: HIGH DISPLACEMENT BISTABLE MICRO ACTUATOR



(57) Abstract: The present invention provides a bistable actuator device formed by thin films for generating mechanical motion in response to an electronic control signal. The present invention combines a thin film bistable mechanical structure with piezoelectric thin film force elements to generate improved force and displacement properties in the actuator device. Applications of the bistable actuator device include, but not limited to, a micro pump, and an electronic switch or relay.

WO 2004/063090 A2

HIGH DISPLACMENT BISTABLE MICRO ACTUATOR

CROSS-REFERENCE TO RELATED APPLICATION(S)

The present utility patent application claims priority of U.S. Provisional Patent Application, Serial No. 60/439,768, filed January 13, 2003, subject matter of which is incorporated herewith by reference.

FIELD OF THE INVENTION

The present invention relates generally to a bistable actuator device, and more particularly, to a solid-state piezoelectric actuator device and improved method for producing mechanical motion.

BACKGROUND OF THE INVENTION

Piezoelectric materials are used in a variety of sensors and actuators. Piezoelectric materials convert mechanical energy to electrical energy and vice versa. For instance, if pressure is applied to a piezoelectric crystal, an electrical signal is generated in proportion thereby producing the function of a sensor. Generation of an electrical signal in response to an applied force or pressure is known as the "primary piezoelectric effect". Similarly, if an electrical signal is applied to a piezoelectric crystal, it will expand in proportion as an actuator. Geometric deformation (expansion or contraction) in response to an applied electric signal is known as the "secondary piezoelectric effect". Whether operated as a sensor or actuator, electrically conductive electrodes must be

appropriately placed on the piezoelectric crystal for collection or application of the electrical signal, respectively. Therefore, a piezoelectric actuator (sensor) consists nominally of a) a portion of piezoelectric material, and b) electrically-conductive electrodes suitably arranged to transfer electrical energy from (to) an external power source.

Piezoelectric materials have been utilized in the art to create a variety of simple sensors and actuators. Examples of sensors include vibration sensors, microphones, and ultrasonic sensors. Examples of actuators include ultrasonic transmitters and linear positioning devices. However, in most of these examples, bulk piezoelectric material is machined and assembled in a coarse manner to achieve low-complexity devices. In cases where bulk piezoelectric materials are used as actuators, a large mechanical motion can only be achieved with very large devices and very high voltages. Operating bulk piezoelectric actuators at high voltages or high power limits the utility of the actuator and also limits the reliability.

Other types of actuators that rely on electrostatic actuation mechanisms can also produce a large mechanical motion only with very high voltages. Operating electrostatic actuators at high voltages or high power limits the utility of the actuator and also limits the reliability. In addition, electrostatic actuation mechanisms produce relatively small forces and have other practical failure complications associated with clamping.

Therefore, there is a need for an improved actuation device capable of producing large mechanical motion without high electrical power requirements and without compromising the device reliability.

SUMMARY OF THE INVENTION

To solve the above and the other problems, the present invention provides a solid-state actuator device, and more particularly a bistable actuator formed by thin films. Similar to silicon Integrated Circuits (ICs), a bistable actuator of the present invention is built up by a series of thin films, typically less than or about 5 microns (0.005 mm) in thickness. A bistable actuator is designed to move between two preferred physical positions upon application of an electrical control signal.

An embodiment of the present invention provides thin-film piezoelectric elements on a bistable mechanical structure to switch the position of the structure upon application of an electrical control signal. Even without any electrical signal applied to the piezoelectric elements the bistable structure, by definition, is stable in one of two positions or mechanical "states". To place the device in a first mechanical state, a first electrical control signal is applied to a first piezoelectric element on the structure. The applied first electrical control signal produces a mechanical force in the first piezoelectric element according to the secondary piezoelectric effect. The first piezoelectric element is positioned on the bistable structure so as to move the device to the first mechanical state upon application of the first electrical control signal. Even after removal of the first

electrical control signal, the bistable structure remains in the first mechanical state. To place the device in a second mechanical state, a second electrical control signal is applied to a second piezoelectric element on the structure. The applied second electrical control signal produces a mechanical force in the second piezoelectric element according to the secondary piezoelectric effect. The second piezoelectric element is positioned on the bistable structure so as to move the device to the second mechanical state upon application of the second electrical control signal. Even after removal of the second electrical control signal, the bistable structure remains in the second mechanical state.

The present invention uses a bistable mechanical structure that has two preferred physical positions. This type of physical structure has several key advantages for creating a variety of actuators:

Force – During an actuation event, the mechanical structure provides additional force in the desired direction, allowing more work to be done by the device.

Displacement – The mechanical structure provides more physical motion during an actuation event, again allowing more work to be done by the device.

Low Power – The mechanical structure retains its position in one of the two stable states even after electrical power is removed, allowing the electronics to "sleep" or "standby" between state switching events.

Reliability – The mechanical structure retains its position even after the electrical power source is removed. In the event of a power outage or interruption, the device retains its state.

The present invention also utilizes piezoelectric materials in a thin-film format. The thin-film distinction enables actuators with a far higher degree of complexity and functionality. Thin-film piezoelectrics offer the following key advantages:

Matching – Thin-film piezoelectric materials are deposited and defined on an atomic scale utilizing fabrication processes common in the semiconductor industry. The result is that thin-film piezoelectric elements can be consistently manufactured with element matching more than 100X better than conventional bulk machined devices.

Density – Thin-film piezoelectric elements are defined using microlithography, a process that allows extremely small dimensions (less than 0.001 mm, or 1 micron) to be delineated in a consistent and controlled manner. The result is that a large number of precision piezoelectric elements can be defined on a single microscopic actuator device.

Low-Cost – Thin-film piezoelectric elements are defined using batch processing techniques common in the semiconductor industry. A typical deposition, pattern transfer, and etch sequence on a single silicon wafer can define literally millions of precision piezoelectric elements on thousands of actuators.

Size – Thin-film piezoelectrics enable far smaller devices to be manufactured.

Low Power – Less energy is required to operate a thin-film device.

The above advantages are inherent to the present invention and enable novel configurations and unique features that increase the overall device and system performance.

These and other features and advantages of the present invention will become apparent to those skilled in the art from the following detailed description, wherein it is shown and described illustrative embodiments of the invention, including best modes contemplated for carrying out the invention. As it will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of one embodiment of a bistable structure showing a first mechanical state, in accordance with the principles of the present invention.

Figure 2 is a cross-sectional view of the embodiment of the bistable structure shown in Figure 1 showing a second mechanical state, in accordance with the principles of the present invention.

Figure 3 is a cross-sectional view of a first embodiment of a bistable actuator device showing one arrangement of piezoelectric force element placement on a circular bistable structure, in accordance with the principles of the present invention.

Figure 4 is a top view of the first embodiment of the bistable actuator device shown in Figure 3.

Figure 5 is a cross-sectional view of a second embodiment of a bistable actuator device showing another arrangement of piezoelectric force element placement on a bridge bistable structure, in accordance with the principles of the present invention.

Figure 6 is a top view of the second embodiment of the bistable actuator device shown in Figure 5.

Figure 7 is a cross-sectional view of a third embodiment of a bistable actuator device showing a further arrangement of piezoelectric force element placement on a circular bistable structure, in accordance with the principles of the present invention.

Figure 8 is a top view of the third embodiment of the bistable actuator device shown in Figure 7.

Figure 9 is a cross-sectional view of a fourth embodiment of a bistable actuator device showing a further arrangement of piezoelectric force element placement on a bridge bistable structure, in accordance with the principles of the present invention.

Figure 10 is a top view of the fourth embodiment of the bistable actuator device shown in Figure 9.

Figure 11 is a cross-sectional view of a fifth embodiment of a bistable actuator device showing a further arrangement of piezoelectric force element placement on a circular bistable structure, in accordance with the principles of the present invention.

Figure 12 is a top view of the fifth embodiment of the bistable actuator device shown in Figure 11.

Figure 13 is a cross-sectional view of a sixth embodiment of a bistable actuator device showing a further arrangement of piezoelectric force element placement on a bridge bistable structure, in accordance with the principles of the present invention.

Figure 14 is a top view of the sixth embodiment of the bistable actuator device shown in Figure 13.

Figure 15 is a cross-sectional view of one embodiment of a bistable actuator device detailing an arrangement of the layers comprising piezoelectric force elements, in accordance with the principles of the present invention.

Figure 16 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a first mechanical state.

Figure 17 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a second mechanical state.

Figure 18 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a third mechanical state.

Figure 19 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a fourth mechanical state.

Figure 20 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a fifth mechanical state.

Figure 21 is a cross-sectional view of an embodiment of a gas or fluid pump according to the principles of the present invention in a sixth mechanical state.

Figure 22 is a cross-sectional view of a first embodiment of an electrical switch according to the principles of the present invention in a first mechanical state comprising an electrical open circuit.

Figure 23 is a cross-sectional view of the first embodiment of an electrical switch according to the principles of the present invention in a second mechanical state comprising an electrical closed circuit.

Figure 24 is a cross-sectional view of a second embodiment of an electrical switch according to the principles of the present invention in a first mechanical state comprising an electrical open circuit.

Figure 25 is a cross-sectional view of the second embodiment of an electrical switch according to the principles of the present invention in a second mechanical state comprising an electrical closed circuit.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a bistable actuator device formed by thin films for generating mechanical motion in response to an electrical control signal. The device includes a bistable structure which has two preferred mechanical states, or positions. The device also includes at least one force element positioned on the bistable structure for the purpose of switching the device between the two mechanical states. The force elements generate a mechanical force when activated by an electrical signal or an electrical control signal, such that the device is switched between the two mechanical states by an electrical control signal.

The main features of one embodiment of a bistable structure are shown in Figure 1 and Figure 2. The structure includes a pre-stressed mechanical support 1 that is suspended on a support substrate 3, the support substrate 3 having a cavity 5. The mechanical support 1 is under compressive stress, said compressive stress being sufficient to produce buckling in the mechanical support 1.

The details of how the compressive pre-stress is created are not specific to this invention. However, one method for producing the compressive pre-stress is

to fix the mechanical support 1 to the support substrate 3 at an elevated temperature, wherein the thermal expansion coefficient of the support substrate 3 is higher than the thermal expansion coefficient of the mechanical support 1. When the temperature of the assembled device is reduced to normal operating levels, the mechanical support 1 will be under compressive stress. The magnitude of compressive stress can be controlled by selecting materials for the mechanical support 1 and support substrate 3 that have an appropriate thermal expansion coefficient mismatch and/or selecting the assembly temperature. Similarly, another method for producing the pre-stress is to fix the mechanical support 1 to the support substrate 3 at a reduced temperature, wherein the thermal expansion coefficient of the support substrate 3 is lower than the thermal expansion coefficient of the mechanical support 1. When the temperature of the assembled device is raised to normal operating levels, the mechanical support 1 will be under compressive stress. The magnitude of compressive stress can be controlled by selecting materials for the mechanical support 1 and support substrate 3 that have an appropriate thermal expansion coefficient mismatch and/or selecting the assembly temperature.

In a preferred thin-film embodiment of the present invention, the support substrate 3 is a silicon wafer with a preferred thickness between 100 microns and 1000 microns. Other suitable materials for the support substrate 3 include, but not limited to, quartz, glass, and galium-arsenide. Also, in the preferred thin-film embodiment, the mechanical support 1 is comprised of a layer of polycrystalline silicon with a preferred thickness between 0.1 microns and 10 microns. Other

suitable materials for the mechanical support 1 include, but not limited to, silicon nitride, silicon dioxide, a variety of metals, or a laminated combination thereof. In one thin-film embodiment, the level of compressive pre-stress in the mechanical support 1 depends on the application requirements, the materials selected, and the temperature at which the mechanical support 1 thin film is deposited. The compressive pre-stress will produce a deflection of the mechanical support 1 perpendicular to the surface of the device. For an application, material set, and device dimensions, the deflection of the mechanical support 1 from the planar position is in the range 0.1 microns to 10 microns. That is, the mechanical support 1 has two preferred (or stable) positions, called "states". Figure 1 shows a first mechanical state, while Figure 2 shows a second mechanical state. The two stable states are formed as a result of the compressive pre-stress in the mechanical support 1. A force acting on the mechanical support 1 can switch the mechanical support 1 from one state to the other.

The main features of a preferred generally circular embodiment of a bistable actuator device according to the present invention are detailed in Figure 3 and Figure 4. Figure 3 shows a representative cross-sectional view, while Figure 4 shows a top view. The circular bistable actuator device is comprised of the mechanical support 1 fixed on the support substrate 3, the support substrate 3 containing the cavity 5. Figure 3 shows one of two mechanical states for the circular bistable actuator device wherein the mechanical support 1 is deflected towards the support substrate 3. A central force element 7 is fixed to the mechanical support 1 over the cavity 5. A peripheral force element 9 is also

fixed to the mechanical support 1 over the cavity 5. Means for electrically contacting the force elements are not shown in Figure 3 or Figure 4 but will be understood by those skilled in the art. When an electrical signal is connected to the central force element 7 or peripheral force element 9, the force elements expand or contract in the x-direction and y-direction, creating a shear stress on the mechanical support 1. The bistable actuator device in Figure 3 is shown in the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3). The bistable actuator device in Figure 3 is switched to the "upward state" (where the mechanical support 1 is deflected away from the support substrate 3) by applying a first electrical signal to the central force element 7 causing the central force element 7 to expand in the surface plane while also applying a second electrical signal to the peripheral force element 9 causing the peripheral force element 9 to contract in the surface plane. Expansion of the central force element 7 causes the mechanical support 1 to bend with downward concavity in the region under the central force element 7. Contraction of the peripheral force element 9 causes the mechanical support 1 to bend with upward concavity in the region under the peripheral force element 9. Similarly, the bistable actuator device in Figure 3 is switched back to the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3) by applying a third electrical signal to the central force element 7 causing the central force element 7 to contract in the surface plane while also applying a fourth electrical signal to the peripheral force element 9 causing the peripheral force element 9 to expand in the surface plane. Contraction of the central force

element 7 causes the mechanical support 1 to bend with upward concavity in the region under the central force element 7. Expansion of the peripheral force element 9 causes the mechanical support 1 to bend with downward concavity in the region under the peripheral force element 9. The bistable actuator device of Figure 3 is switched between mechanical states by applying suitable electrical signals to the central force element 7 and peripheral force element 9.

The main features of a preferred generally rectangular embodiment of a bistable actuator device according to the present invention are detailed in Figure 5 and Figure 6. Figure 5 shows a representative cross-sectional view, while Figure 6 shows a top view. The rectangular bistable actuator device is comprised of a mechanical support 11 fixed on a support substrate 13, the support substrate 13 containing a cavity 15. Figure 5 shows one of two mechanical states for the rectangular bistable actuator device wherein the mechanical support 11 is deflected towards the support substrate 13. A central force element 17 is fixed to the mechanical support 11 over the cavity 15. Peripheral force elements 19 and 21 are also fixed to the mechanical support 11 over the cavity 15. Means for electrically contacting the force elements 17, 19 and 21 are not shown in Figure 5 or Figure 6 but will be understood by those skilled in the art. When an electrical signal is connected to the central force element 17 or peripheral force elements 19 and 21, the force elements expand or contract in the x-direction and y-direction, creating a shear stress on the mechanical support 11. The bistable actuator device in Figure 5 is shown in the "downward state" (where the mechanical support 11 is deflected towards the support substrate 13). The bistable actuator device in

Figure 5 is switched to the "upward state" (where the mechanical support 11 is deflected away from the support substrate 13) by applying a first electrical signal to the central force element 17 causing the central force element 17 to expand in the surface plane while also applying a second electrical signal to the peripheral force elements 19 and 21 causing the peripheral force elements 19 and 21 to contract in the surface plane. Expansion of the central force element 17 causes the mechanical support 11 to bend with downward concavity in the region under the central force element 17. Contraction of the peripheral force elements 19 and 21 causes the mechanical support 11 to bend with upward concavity in the region under the peripheral force elements 19 and 21. Similarly, the bistable actuator device in Figure 5 is switched back to the "downward state" (where the mechanical support 11 is deflected towards the support substrate 13) by applying a third electrical signal to the central force element 17 causing the central force element 17 to contract in the surface plane while also applying a fourth electrical signal to the peripheral force elements 19 and 21 causing the peripheral force elements 19 and 21 to expand in the surface plane. Contraction of the central force element 17 causes the mechanical support 11 to bend with upward concavity in the region under the central force element 17. Expansion of the peripheral force elements 19 and 21 causes the mechanical support 11 to bend with downward concavity in the region under the peripheral force elements 19 and 21. The bistable actuator device of Figure 5 is switched between mechanical states by applying suitable electrical signals to the central force element 17 and peripheral force elements 19 and 21.

The main features of another generally circular embodiment of a bistable actuator device according to the present invention are detailed in Figure 7 and Figure 8. Figure 7 shows a representative cross-sectional view, while Figure 8 shows a top view. The circular bistable actuator device of Figure 7 is comprised of the mechanical support 1 fixed on the support substrate 3, the support substrate containing the cavity 5. Figure 7 shows one of two mechanical states for the circular bistable actuator device wherein the mechanical support 1 is deflected towards the support substrate 3. A peripheral force element 23 is fixed to the mechanical support 1 over the cavity 5. Means for electrically contacting the force element 23 is not shown in Figure 7 or Figure 8 but will be understood by those skilled in the art. When an electrical signal is connected to the peripheral force element 23, the peripheral force element expands or contracts in the x-direction and y-direction, creating a shear stress on the mechanical support 1. The bistable actuator device in Figure 7 is shown in the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3). The bistable actuator device in Figure 7 is switched to the "upward state" (where the mechanical support 1 is deflected away from the support substrate 3) by applying a first electrical signal to the peripheral force element 23 causing the peripheral force element 23 to contract in the surface plane. Contraction of the peripheral force element 23 causes the mechanical support 1 to bend with upward concavity in the region under the peripheral force element 23. Similarly, the bistable actuator device in Figure 7 is switched back to the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3) by applying a

second electrical signal to the peripheral force element 23 causing it to expand in the surface plane. Expansion of the peripheral force element 23 causes the mechanical support 1 to bend with downward concavity in the region under the peripheral force element 23. The bistable actuator device of Figure 7 is switched between mechanical states by applying first or second electrical signals to the peripheral force element 23.

The main features of another generally rectangular embodiment of a bistable actuator device according to the present invention are detailed in Figure 9 and Figure 10. Figure 9 shows a representative cross-sectional view, while Figure 10 shows a top view. The rectangular bistable actuator device of Figure 9 is comprised of the mechanical support 11 fixed on the support substrate 13, the support substrate containing the cavity 15. Figure 9 shows one of two mechanical states for the rectangular bistable actuator device wherein the mechanical support 11 is deflected towards the support substrate 13. Peripheral force elements 25 and 27 are fixed to the mechanical support 11 over the cavity 15. Means for electrically contacting the force elements are not shown in Figure 9 or Figure 10 but will be understood by those skilled in the art. When an electrical signal is connected to the peripheral force elements 25 and 27, the peripheral force elements 25 and 27 expand or contract in the x-direction and y-direction, creating shear stress on the mechanical support 11. The bistable actuator device in Figure 9 is shown in the “downward state” (where the mechanical support 11 is deflected towards the support substrate 13). The bistable actuator device in Figure 9 is switched to the “upward state” (where the

mechanical support 11 is deflected away from the support substrate 13) by applying a first electrical signal to the peripheral force elements 25 and 27 causing the peripheral force elements 25 and 27 to contract in the surface plane. Contraction of the peripheral force elements 25 and 27 causes the mechanical support 11 to bend with upward concavity in the region under the peripheral force elements 25 and 27. Similarly, the bistable actuator device in Figure 9 is switched back to the "downward state" (where the mechanical support 11 is deflected towards the support substrate 13) by applying a second electrical signal to the peripheral force elements 25 and 27 causing the peripheral force elements 25 and 27 to expand in the surface plane. Expansion of the peripheral force elements 25 and 27 causes the mechanical support 11 to bend with downward concavity in the regions under the peripheral force elements 25 and 27. The bistable actuator device of Figure 9 is switched between mechanical states by applying first or second electrical signals to the peripheral force elements 25 and 27.

The main features of another generally circular embodiment of a bistable actuator device according to the present invention are detailed in Figure 11 and Figure 12. Figure 11 shows a representative cross-sectional view, while Figure 12 shows a top view. The circular bistable actuator device of Figure 11 is comprised of the mechanical support 1 fixed on the support substrate 3, the support substrate containing the cavity 5. Figure 11 shows one of two mechanical states for the circular bistable actuator device wherein the mechanical support 1 is deflected towards the support substrate 3. A central force element 29

is fixed to the mechanical support 1 over the cavity 5. Means for electrically contacting the force element 29 is not shown in Figure 11 or Figure 12 but will be understood by those skilled in the art. When an electrical signal is connected to the central force element 29, the central force element 29 expands or contracts in the x-direction and y-direction, creating a shear stress on the mechanical support 1. The bistable actuator device in Figure 11 is shown in the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3). The bistable actuator device in Figure 11 is switched to the "upward state" (where the mechanical support 1 is deflected away from the support substrate 3) by applying a first electrical signal to the central force element 29 causing the central force element 29 to expand in the surface plane. Expansion of the central force element 29 causes the mechanical support 1 to bend with downward concavity in the region under the central force element 29. Similarly, the bistable actuator device in Figure 11 is switched back to the "downward state" (where the mechanical support 1 is deflected towards the support substrate 3) by applying a second electrical signal to the central force element 29 causing the central force element 29 to contract in the surface plane. Contraction of the central force element 29 causes the mechanical support 1 to bend with upward concavity in the region under the central force element 29. The bistable actuator device of Figure 11 is switched between mechanical states by applying first or second electrical signals to the central force element 29.

The main features of another generally rectangular embodiment of a bistable actuator device according to the present invention are detailed in Figure

13 and Figure 14. Figure 13 shows a representative cross-sectional view, while Figure 14 shows a top view. The rectangular bistable actuator device of Figure 13 is comprised of the mechanical support 11 fixed on the support substrate 13, the support substrate containing the cavity 15. Figure 13 shows one of two mechanical states for the rectangular bistable actuator device wherein the mechanical support 11 is deflected towards the support substrate 13. A central force element 31 is fixed to the mechanical support 11 over the cavity 15. Means for electrically contacting the force element is not shown in Figure 13 or Figure 14 but will be understood by those skilled in the art. When an electrical signal is connected to the central force element 31, the central force element 31 expands or contracts in the x-direction and y-direction, creating a shear stress on the mechanical support 11. The bistable actuator device in Figure 13 is shown in the "downward state" (where the mechanical support 11 is deflected towards the support substrate 13). The bistable actuator device in Figure 13 is switched to the "upward state" (where the mechanical support 11 is deflected away from the support substrate 13) by applying a first electrical signal to the central force element 31 causing the central force element 31 to expand in the surface plane. Expansion of central force element 31 causes the mechanical support 11 to bend with downward concavity in the region under the central force element 31. Similarly, the bistable actuator device in Figure 13 is switched back to the "downward state" (where the mechanical support 11 is deflected towards the support substrate 13) by applying a second electrical signal to the central force element 31 causing the central force element to contract in the surface plane.

Contraction of the central force element 31 causes the mechanical support 11 to bend with upward concavity in the region under the central force element 31. The bistable actuator device of Figure 13 is switched between mechanical states by applying first or second electrical signals to the central force element 31.

Several embodiments of a bistable actuator device are depicted in Figures 3 – 14. In each of these figures, the specific details of the force elements were not discussed. There are many ways to implement thin-film force elements that are capable of producing the required planar expansion or contraction necessary to switch the mechanical state of the bistable actuator device.

A preferred embodiment of the force elements is detailed in Figure 15. In Figure 15, the device is depicted in a planar condition for simplicity; i.e. between mechanical states. Figure 15 shows a representative cross-sectional view of a bistable actuator device comprised of a mechanical support 41 fixed on a support substrate 43, the support substrate containing a cavity 45. The bistable actuator device shown in Figure 15 is further comprised of a conductive central force element electrode 53, a conductive peripheral force element electrode 55, a conductive lower force element electrode 47, a layer of piezoelectric material 49, and a dielectric layer 51. Metal connections 57, 59, and 61 provide means for electrically connecting the conductive central force element electrode 53, conductive peripheral force element electrode 55, and conductive lower force element electrode 47, respectively, to external electrical signals. The preferred piezoelectric layer 49 material is PZT, although other materials, such as ZnO, quartz, AlN, and $BaTiO3$, may also be used. The preferred material for the

conductive electrodes 53, 55, and 47 is platinum (Pt) although other materials, such as RuO, IrO, and Au, may also be used. The preferred material for the dielectric layer 51 is silicon dioxide although other materials, such as silicon nitride, may also be used. The preferred material for the electrical connections 57, 59, and 61 is gold although other materials, such as aluminum, titanium nitride, and chrome, may also be used.

The preferred piezoelectric state switching mechanism for the bistable actuator in Figure 15 is to utilize the secondary piezoelectric effect for both expansion and contraction of the force elements 53, 55, and 47. The bistable actuator device shown in Figure 15 is similar to Figure 3 and Figure 4. In Figure 15, the conductive central force element electrode 53 in conjunction with the conductive lower force element electrode 47 and layer of piezoelectric material 49 defines a first force element fixed to the mechanical support 41 and corresponds to the central force element 7 fixed to the mechanical support 1 in Figure 3 and Figure 4. Similarly, the conductive peripheral force element electrode 55 in conjunction with the conductive lower force element electrode 47 and layer of piezoelectric material 49 defines a second force element fixed to the mechanical support 41 and corresponds to the peripheral force element 9 fixed to the mechanical support 1 in Figure 3 and Figure 4. The first and second force elements share a common electrical connection by virtue of the conductive lower force element electrode 47. However, since the layer of piezoelectric material 49 is non-conductive, the force element electrodes 53 and 55 are electrically isolated and operate independently over most practical frequency ranges. The portion of

the layer of the piezoelectric material 49 under the central force element electrode 53 expands in the x-and y-directions by applying a first voltage polarity to the electrical connection 59 while applying a ground reference voltage to the electrical connection 57 by virtue of the secondary piezoelectric effect. The portion of the layer of the piezoelectric material 49 under the central force element electrode 53 contracts in the x-and y-directions by applying a second voltage polarity to the electrical connection 59 while applying a ground reference voltage to the electrical connection 57 by virtue of the secondary piezoelectric effect. The portion of the layer of the piezoelectric material 49 under the peripheral force element electrode 55 expands in the x-and y-directions by applying a first voltage polarity to the electrical connection 61 while applying a ground reference voltage to the electrical connection 57 by virtue of the secondary piezoelectric effect. The portion of the layer of the piezoelectric material 49 under the peripheral force element electrode 55 contracts in the x-and y-directions by applying a second voltage polarity to the electrical connection 61 while applying a ground reference voltage to the electrical connection 57 by virtue of the secondary piezoelectric effect. Similar to the embodiment of Figure 3 and Figure 4, the bistable actuator device in Figure 15 is switched to the "upward state" (where the mechanical support 41 is deflected away from the support substrate 43) by applying a first voltage polarity to the electrical connection 59 causing the portion of the layer of the piezoelectric material 49 under the central force element electrode 53 to expand in the surface plane while also applying a second voltage polarity to the electrical connection 61 causing the

portion of the layer of the piezoelectric material 49 under the peripheral force element electrode 55 to contract in the surface plane. Expansion of the piezoelectric material 49 causes the mechanical support 41 to bend with downward concavity in the region under the central force element electrode 53. Contraction of the piezoelectric material 49 causes the mechanical support 41 to bend with upward concavity in the region under the peripheral force element electrode 55. Conversely, the bistable actuator device in Figure 15 is switched to the "downward state" (where the mechanical support 41 is deflected towards the support substrate 43) by applying a second voltage polarity to the electrical connection 59 causing the portion of the layer of the piezoelectric material 49 under the central force element electrode 53 to contract in the surface plane while also applying a first voltage polarity to the electrical connection 61 causing the portion of the layer of the piezoelectric material 49 under the peripheral force element electrode 55 to expand in the surface plane. Contraction of the piezoelectric material 49 causes the mechanical support 41 to bend with upward concavity in the region under the central force element electrode 53. Expansion of the piezoelectric material 49 causes the mechanical support 41 to bend with downward concavity in the region under the peripheral force element electrode 55. By applying suitable electrical signals to the connections 59 and 61 relative to the connection 57, the bistable actuator device of Figure 15 is switched between mechanical states according to the secondary piezoelectric effect.

Some piezoelectric actuator materials are limited to unipolar operation. That is, they are only operated with a single voltage polarity to generate either

contraction or expansion. The principles of the present invention include unipolar operation of the piezoelectric force elements.

A further embodiment of piezoelectric state switching for the bistable actuator in Figure 15 is to utilize the secondary piezoelectric effect for just contraction of the force elements. Similar to the embodiment of Figure 3 and Figure 4, the bistable actuator device in Figure 15 is switched to the "upward state" (where the mechanical support 41 is deflected away from the support substrate 43) by applying a first voltage polarity to the electrical connection 61 causing the portion of layer of the piezoelectric material 49 under the peripheral force element electrode 55 to contract in the surface plane. Contraction of the piezoelectric material 49 causes the mechanical support 41 to bend with upward concavity in the region under the peripheral force element electrode 55. Conversely, the bistable actuator device in Figure 15 is switched to the "downward state" (where the mechanical support 41 is deflected towards the support substrate 43) by applying a first voltage polarity to the electrical connection 59 causing the portion of piezoelectric material 49 under the central force element electrode 53 to contract in the surface plane. Contraction of the piezoelectric material 49 causes the mechanical support 41 to bend with upward concavity in the region under the central force element electrode 53. By applying suitable electrical signals to either the connection 59 or 61 relative to the connection 57, the bistable actuator device of Figure 15 is switched between the two mechanical states according to the secondary piezoelectric effect.

A further embodiment of piezoelectric state switching for the bistable actuator in Figure 15 is to utilize the secondary piezoelectric effect for just expansion of the force elements. Similar to the embodiment of Figure 3 and Figure 4, the bistable actuator device in Figure 15 is switched to the "upward state" (where the mechanical support 41 is deflected away from the support substrate 43) by applying a second voltage polarity to the electrical connection 59 causing the portion of the piezoelectric material 49 under the central force element electrode 53 to expand in the surface plane. Expansion of the piezoelectric material 49 causes the mechanical support 41 to bend with downward concavity in the region under the central force element electrode 53. Conversely, the bistable actuator device in Figure 15 is switched to the "downward state" (where the mechanical support 41 is deflected towards the support substrate 43) by applying a second voltage polarity to the electrical connection 61 causing the portion of the piezoelectric material 49 under the peripheral force element electrode 55 to expand in the surface plane. Expansion of the piezoelectric material 49 causes the mechanical support 41 to bend with downward concavity in the region under the peripheral force element electrode 55. By applying suitable electrical signals to either the connection 59 or 61 relative to the connection 57, the bistable actuator device of Figure 15 is switched between the two mechanical states according to the secondary piezoelectric effect.

There are other methods within the scope of the present invention to implement a thin-film force element that provides in-plane expansion or

contraction necessary to switch the mechanical state of the bistable actuator device. One sample is to utilize the electrostrictive properties of some materials to create planar expansion or contraction in response to a large electrical field. Such electric fields can be produced using modest voltages (5-50 Volts) across a thin film (thickness 0.1 – 5 microns). Electrostrictive force elements may be comprised of an electrostrictive material sandwiched between two conductive electrodes. Means for electrically contacting the conductive electrodes are understood by those skilled in the art. Another example for creating the force elements is to use a resistive heater. Upon application of an electrical current, the temperature of the heater and nearby device elements will increase. If the thermal expansion coefficients of the heater (force) element and mechanical support do not match, a shear force is resolved to produce the desired mechanical switching event. A further example for creating the force elements is to use a series of interdigitated conducting electrodes wherein an electric voltage applied between adjacent electrodes produces an in-plane electrostatic attraction. The electrostatic attractive force generates an in-plane contraction to produce the desired mechanical switching event. Also, there are other methods known in the art for generating the desired forces to switch the state of the bistable actuator in accordance with the present invention. The preferred embodiment shown in Figure 15 and described above is one such method and is not intended to limit the scope of the present invention.

Figures 16-21 show a series of cross-sectional views detailing how the present invention can be utilized to create a fluid or gas pump. The device in

Figures 16-21 includes a lower support substrate 69 and an upper support substrate 71 with an incoming flow channel 83 and an outgoing flow channel 85. Three bistable actuators are utilized to create a pump. An incoming valve 73 is created by a first bistable actuator in conjunction with the upper support substrate 71 and incoming flow channel 83. The incoming valve 73 is open when the first bistable actuator is in a "downward" state and is closed when the first bistable actuator is in an "upward" state. An outgoing valve 77 is created by a second bistable actuator in conjunction with the upper support substrate 71 and outgoing flow channel 85. The outgoing valve 77 is open when the second bistable actuator is in a "downward" state and is closed when the second bistable actuator is in an "upward" state. A displacement chamber 75 is created by a third bistable actuator in conjunction with the upper support substrate 71. The displacement chamber 75 volume is maximized when the third bistable actuator is in a "downward" state and minimized when the third bistable actuator is in an "upward" state. A first lateral flow channel 79 between the incoming valve 73 and the displacement chamber 75 permits gas or fluid to pass between them. A second lateral flow channel 81 between the outgoing valve 77 and the displacement chamber 75 permits gas or fluid to pass between them. A preferred embodiment of a pump operation includes a sequence of six mechanical states and is shown in Figures 16 – 21. The first mechanical state of the pump operation is shown in Figure 16 wherein the outgoing valve 77 is open, the incoming valve 73 is closed, and the displacement chamber 75 volume is maximized. The second mechanical state of the pump operation is shown in

Figure 17 wherein the outgoing valve 77 is open, the incoming valve 73 is closed, and the displacement chamber 75 volume is minimized. As the pump transitions from the first to second mechanical state, the volume of the displacement chamber 75 is reduced, and fluid or gas is expelled out through the open outgoing valve 77. The third mechanical state of the pump operation is shown in Figure 18 wherein the outgoing valve 77 is closed, the incoming valve 73 is closed, and the displacement chamber 75 volume is minimized. The fourth mechanical state of the pump operation is shown in Figure 19 wherein the outgoing valve 77 is closed, the incoming valve 73 is open, and the displacement chamber 75 volume is minimized. The fifth mechanical state of the pump operation is shown in Figure 20 wherein the outgoing valve 77 is closed, the incoming valve 73 is open, and the displacement chamber 75 volume is maximized. During the fourth and fifth mechanical states, fluid or gas flows in through the incoming flow channel 83. Note that an alternative embodiment would be to skip the fourth mechanical state in Figure 19 and transition directly from the third mechanical state shown in Figure 18 to the fifth mechanical state shown in Figure 20. The sixth mechanical state for pump operation is shown in Figure 21 wherein the outgoing valve 77 is closed, the incoming valve 73 is closed, and the displacement chamber 75 volume is maximized. After the sixth mechanical state of the pump operation is completed, the device shown in Figure 21 returns to the first mechanical state of the pump operation shown in Figure 16, and the sequence repeats. The bistable actuator configuration shown in Figure 15 is preferred for creating each of the incoming valve 73, outgoing valve 77, and displacement chamber 75. An

advantage of the present invention when used as a gas or fluid pump is the large change in volume of the displacement chamber that increases the pump efficiency. A further advantage of the present invention when used as a gas or fluid pump is the large displacement of the incoming valve 73 and outgoing valve 77. Large displacement in the valves increases both the reliability and efficiency of the pump.

Figure 22 and Figure 23 show a pair of cross-sectional views detailing an embodiment of an electrical switch or relay in accordance with the principles of the present invention. The device shown in Figure 22 and Figure 23 includes a lower support substrate 87 and an upper support substrate 89. A bistable actuator 91 is utilized to open or close the electrical connection between a first conductive electrode 95 residing on the opposing face of the upper support substrate 89 and a second conductive electrode 93 residing on the bistable actuator 91. Means for electrically connecting the bistable actuator 91 to an external control circuit is not shown in Figure 22 or Figure 23 as it is understood by those skilled in the art. Furthermore, means for connecting the first conductive electrode 95 and second conductive electrode 93 to an external electrical circuit are not shown in Figure 22 or Figure 23 as it is understood by those skilled in the art. When the bistable actuator 91 is in a downward state as shown in Figure 22, the first conductive electrode 95 and the second conductive electrode 93 are not in physical contact, and the electrical circuit is open. Conversely, when the bistable actuator 91 is in an upward state as shown in Figure 23, the first conductive electrode 95 and the second conductive electrode 93 are in physical contact, and the electrical circuit

is closed. In this manner, the bistable actuator provides means for creating an electrical switch or relay. An advantage of the present invention when used as an electrical switch or relay is the large displacement of the second conductive electrode 93. When the electrical switch is open, the large separation between the second conductive electrode 93 and the first conductive electrode 95 minimizes the parasitic capacitance. Moreover, when the electrical switch is closed, the large displacement and force of the bistable actuator provide a more reliable and lower resistance contact.

Figure 24 and Figure 25 show a pair of cross-sectional views detailing another embodiment of an electrical switch or relay in accordance with the principles of the present invention. The device shown in Figure 24 and Figure 25 includes a lower support substrate 87 and an upper support substrate 89. A bistable actuator 91 is utilized to open or close the electrical connection between a first conductive electrode 97 and a second conductive electrode 99, both residing on the opposing face of the upper support substrate 89. A third conductive electrode 93 is fixed on the bistable actuator 91 opposite both the first conductive electrode 97 and second conductive electrode 99. Means for electrically connecting the bistable actuator 91 to an external control circuit is not shown in Figure 24 or Figure 25 as it is understood by those skilled in the art. Furthermore, means for connecting the first conductive electrode 97 and second conductive electrode 99 to an external electrical circuit are not shown in Figure 24 or Figure 25 as it is understood by those skilled in the art. When the bistable actuator 91 is in a downward state as shown in Figure 24, there is no conductive

circuit path between the first conductive electrode 97 and the second conductive electrode 99, and the electrical circuit is open. Conversely, when the bistable actuator 91 is in an upward state as shown in Figure 25, the third conductive electrode 93 is in physical contact with both the first conductive electrode 97 and the second conductive electrode 99 to create a conductive circuit path, and the electrical circuit is closed. In this manner, the bistable actuator provides further means for creating an electrical switch or relay. An advantage of the present invention when used as an electrical switch or relay is the large displacement of the third conductive electrode 93. When the electrical switch is open, the large separation between third conductive electrode 93 and first conductive electrode 97 as well as the large separation between the third conductive electrode 93 and the second conductive electrode 99 minimizes the parasitic capacitance. Moreover, when the electrical switch is closed, the large displacement and force of the bistable actuator provide a more reliable and lower resistance contact.

From the above description and drawings, it will be understood by those of ordinary skill in the art that the particular embodiments shown and described are for purposes of illustration only and are not intended to limit the scope of the present invention. Those of ordinary skill in the art will recognize that the present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. References to details of particular embodiments are not intended to limit the scope of the invention.

CLAIMS

What is claimed is:

1. A solid-state actuator device, comprising:

a thin-film mechanical member under compressive stress, the compressive stress providing a plurality of stable mechanical positions for the mechanical member; and

a transducer fixed to the mechanical member generating a force in response to an electronic control signal wherein application of the electronic control signal generates a force to switch the mechanical member between the plurality of stable mechanical positions.

2. A solid-state actuator device, comprising:

a support substrate;

a mechanical member fixed to the support substrate at a plurality of positions to generate a compressive stress in the mechanical member and a plurality of stable mechanical positions substantially perpendicular to the support substrate;

a transducer fixed to the mechanical member for generating a force;

means for connecting the transducer to an electronic control signal;

wherein application of the electronic control signal to the transducer switches the mechanical member between the plurality of stable mechanical positions substantially perpendicular to the support substrate.

3. The solid-state actuator device of claim 2, wherein the mechanical member is suspended from the support substrate and comprises a thin-film plate fixed to the support substrate on opposing sides.

4. The solid-state actuator device of claim 2, wherein the mechanical member comprises a thin-film membrane fixed to a side of the support substrate.

5. The solid-state actuator device of claim 4, wherein the thin-film membrane is circular.

6. The solid-state actuator device of claim 2, wherein the transducer is a piezoelectric capacitor fixed along a portion of the mechanical member and comprises:

a lower conductive electrode;

an upper conductive electrode; and

a piezoelectric layer fixed between the lower and upper conductive electrodes.

7. The solid-state actuator device of claim 6, wherein the piezoelectric layer is comprised of PZT.

8. The solid-state actuator device of claim 6, wherein the piezoelectric layer is comprised of ZnO.

9. The solid-state actuator device of claim 6, wherein the piezoelectric layer is comprised of AlN.

10. The solid-state actuator of claim 2 wherein the transducer is fixed along a central portion of the mechanical member.

11. The solid-state actuator of claim 2 wherein the transducer is fixed along a peripheral portion of the mechanical member.

12. The solid-state actuator of claim 2, further comprising a second transducer fixed to the mechanical member for generating a force wherein the first transducer switches the mechanical member to a first stable mechanical position and the second transducer alternatively switches the mechanical member to a second stable mechanical position.

13. The solid-state actuator of claim 2 wherein the mechanical member remains at one of the plurality of stable mechanical positions after removal of the electronic control signal.

14. A solid-state valve for opening/closing a flow channel, comprising:

a support substrate;

a mechanical member fixed to the support substrate at a plurality of positions to generate a compressive stress in the mechanical member and a plurality of stable mechanical positions substantially perpendicular to the support substrate;

a first stable mechanical position closing the flow channel;

a second stable mechanical position opening the flow channel;

a transducer fixed to the mechanical member for generating a force;

means for connecting the transducer to an electronic control signal;

wherein application of a first electronic control signal to the transducer switches the mechanical member to the first stable mechanical

position thereby closing the flow channel whereas application of a second electronic control signal to the transducer switches the mechanical member to the second stable mechanical position thereby opening the flow channel.

15. A solid-state relay for opening/closing an electrical circuit, comprising:

a support substrate;

a mechanical member fixed to the support substrate at a plurality of positions to generate a compressive stress in the mechanical member and a plurality of stable mechanical positions substantially perpendicular to the support substrate;

a first conductive electrode fixed on the mechanical member and a second conductive electrode;

a first stable mechanical position moving the first conductive electrode into contact with the second conductive electrode to close the electrical circuit;

a second stable mechanical position moving the first conductive electrode out of contact with the second conductive electrode to open the electrical circuit;

a transducer fixed to the mechanical member for generating a force;

means for connecting the transducer to an electronic control signal;

wherein application of a first electronic control signal to the transducer switches the mechanical member to the first stable mechanical position thereby closing the electrical circuit whereas application of a second

electronic control signal to the transducer switches the mechanical member to the second stable mechanical position thereby opening the electrical circuit.

16. A solid-state pump for displacing gas/fluid, comprising:

a support substrate;

a mechanical member fixed to the support substrate at a plurality of positions to generate a compressive stress in the mechanical member and a plurality of stable mechanical positions substantially perpendicular to the support substrate;

a cavity in the support substrate surrounding on at least one side of the mechanical member;

a first stable mechanical position increasing volume of the cavity;

a second stable mechanical position decreasing the volume of the cavity;

a transducer fixed to the mechanical member for generating a force;

means for connecting the transducer to an electronic control signal;

wherein application of a first electronic control signal to the force transducer switches the mechanical member to the first stable mechanical position thereby increasing the volume of the cavity whereas application of a second electronic control signal to the transducer switches the mechanical member to the second stable mechanical position thereby decreasing the volume of the cavity.

17. The solid-state pump of claim 16 further comprising a flow channel into the cavity.

FIGURE 1

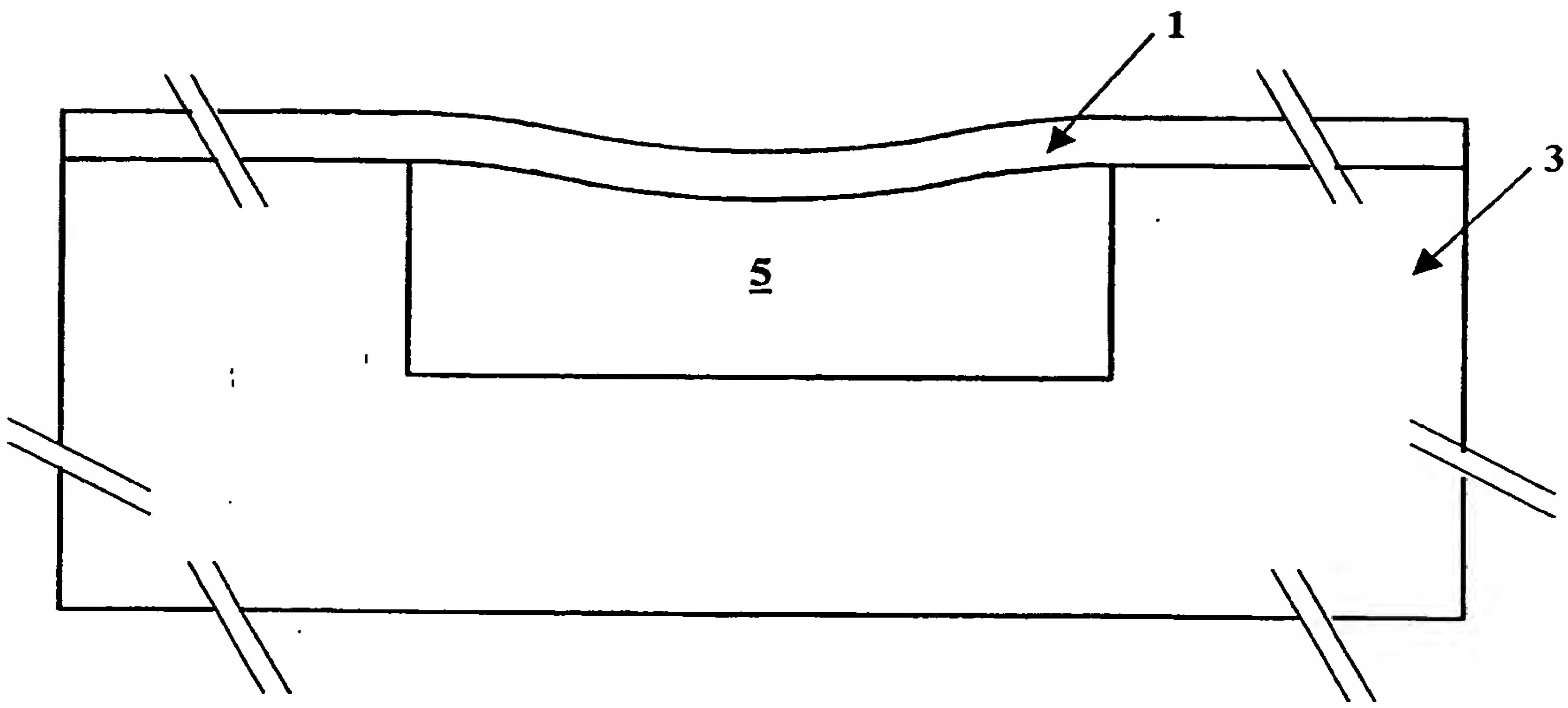


FIGURE 2

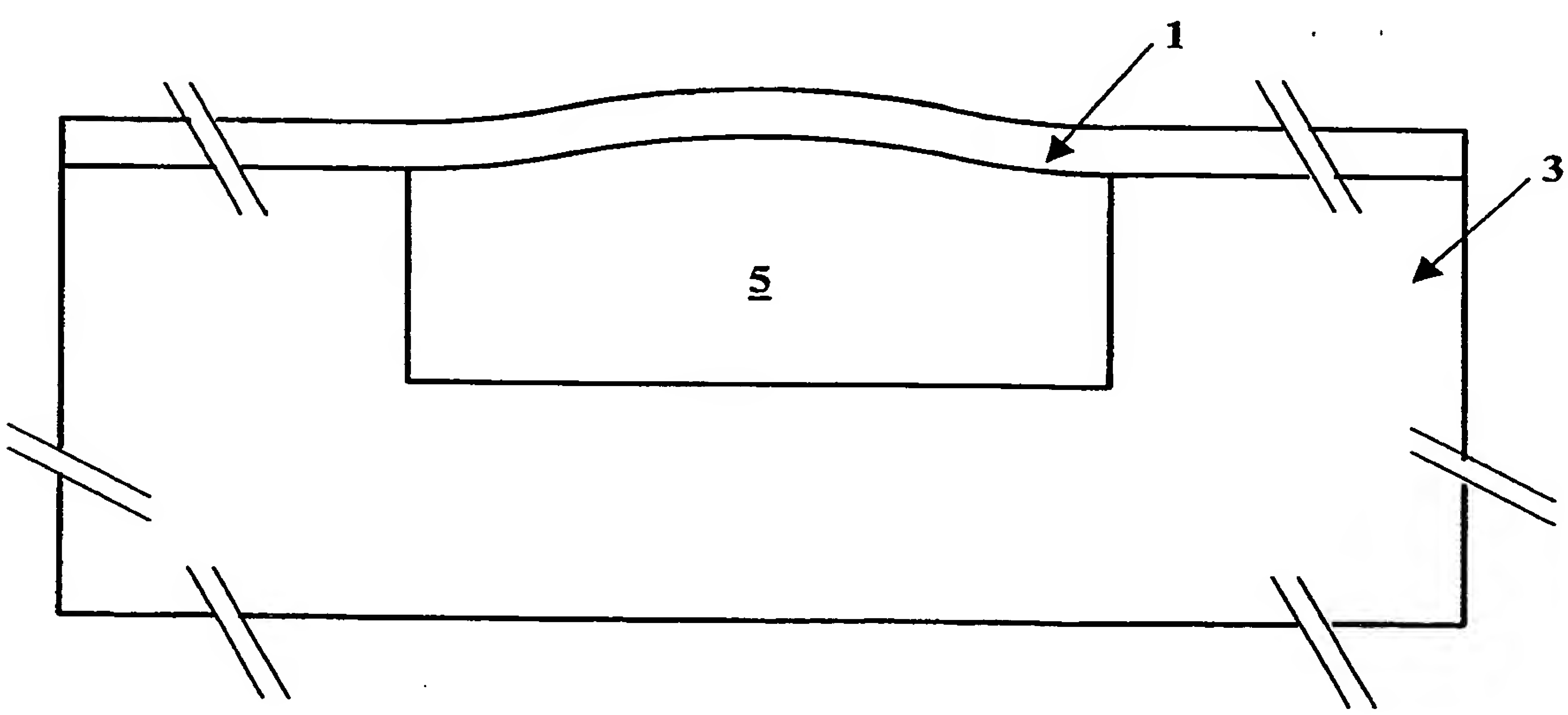


FIGURE 3

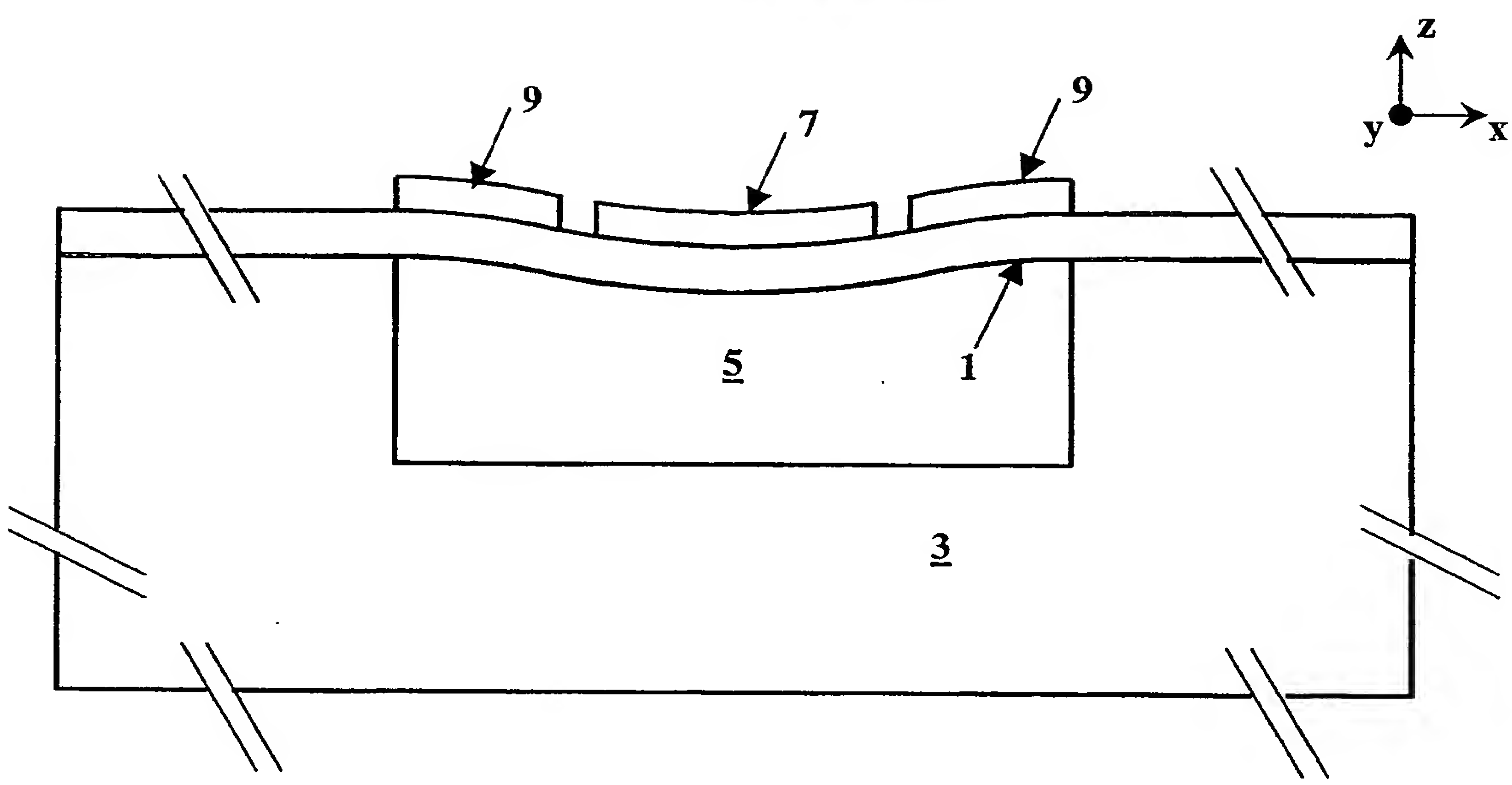


FIGURE 4

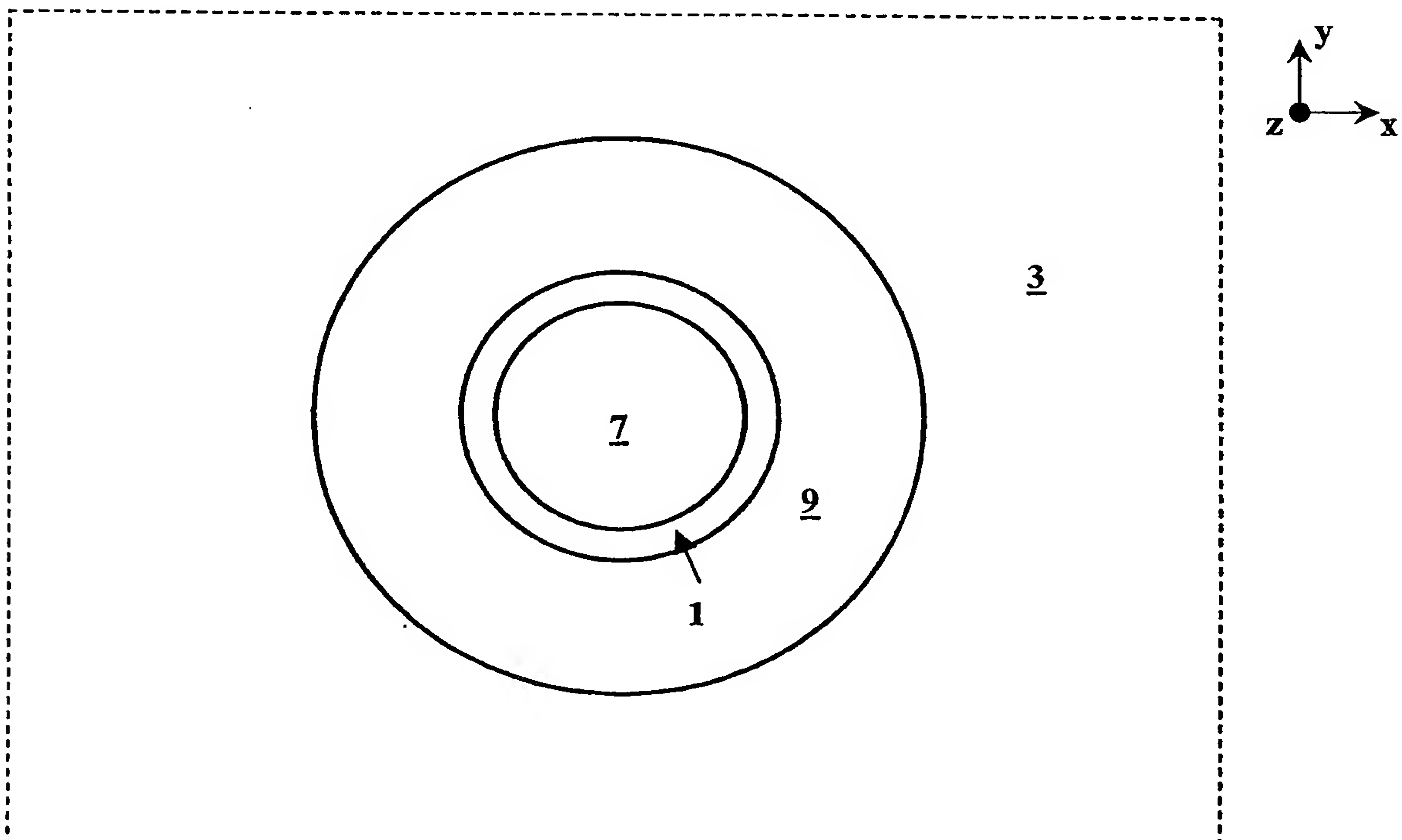


FIGURE 5

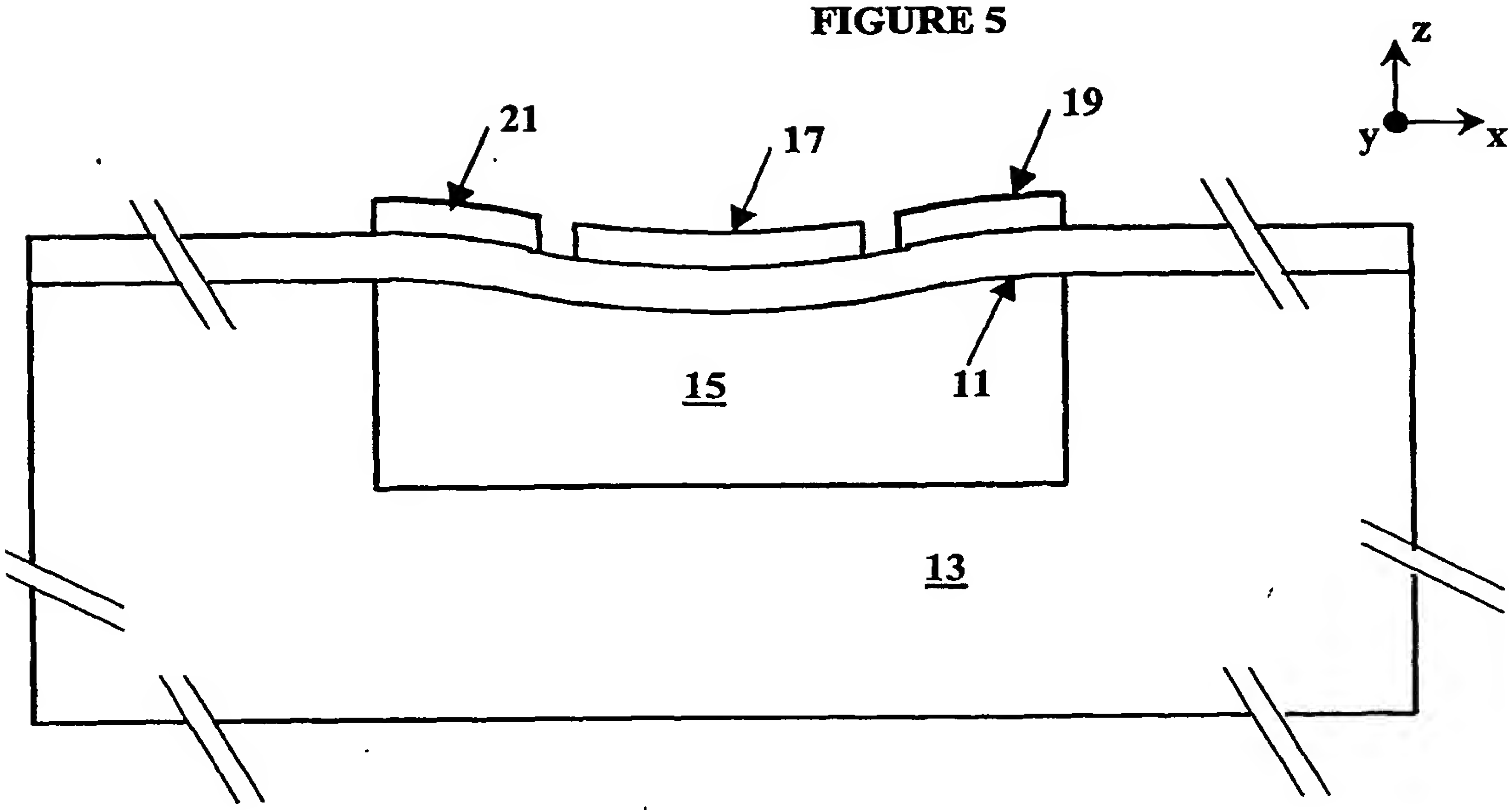


FIGURE 6

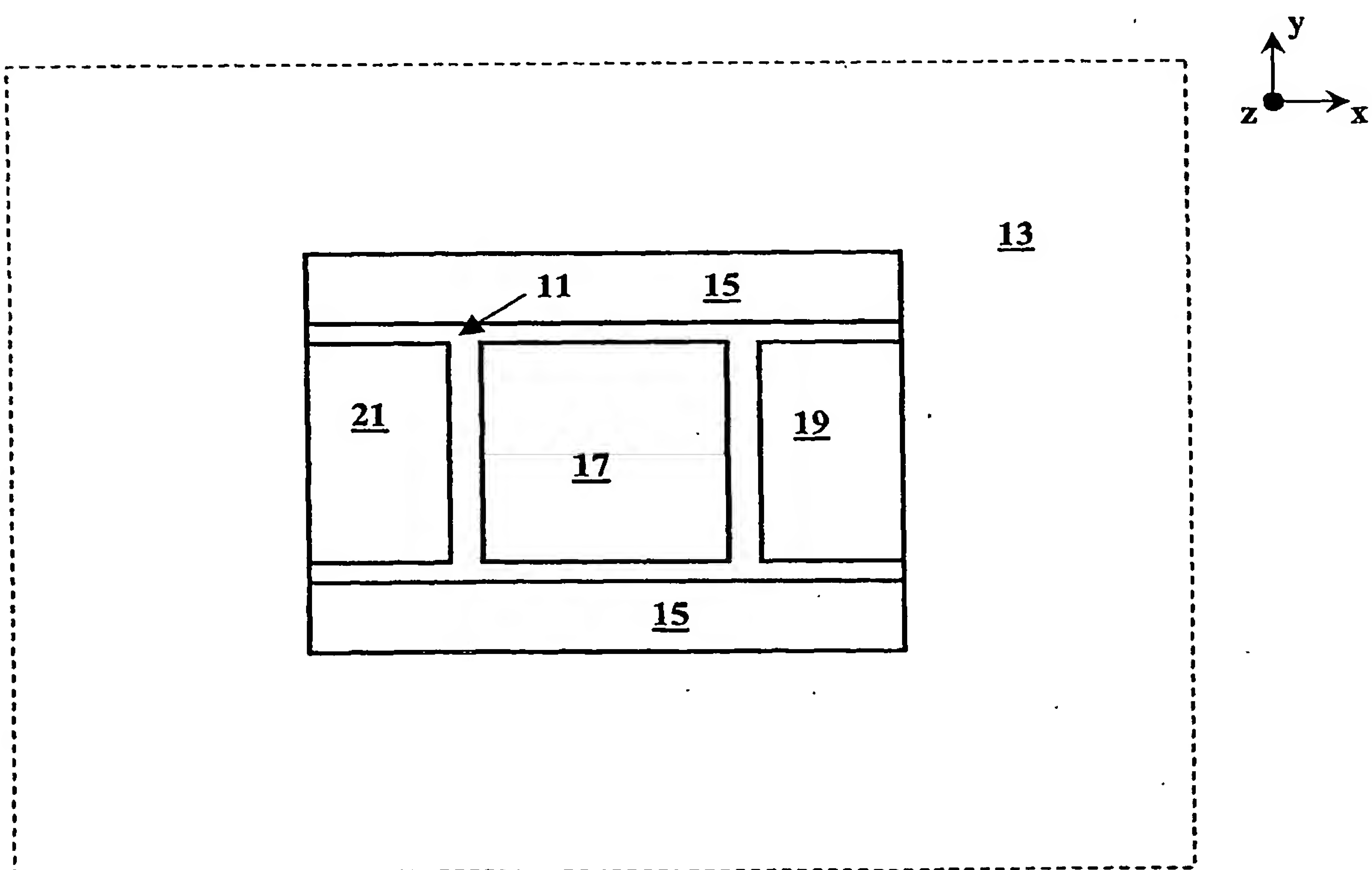


FIGURE 7

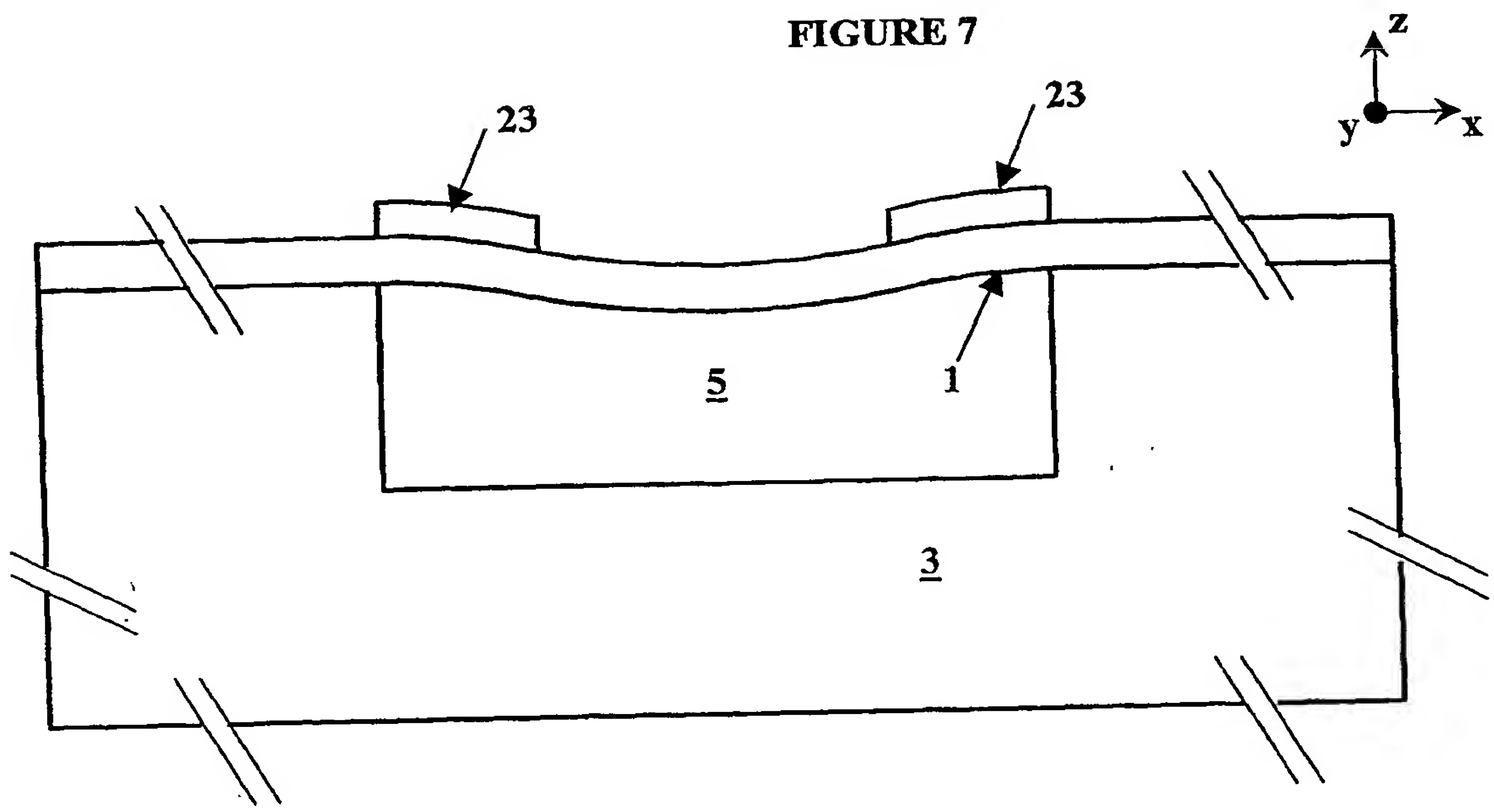


FIGURE 8

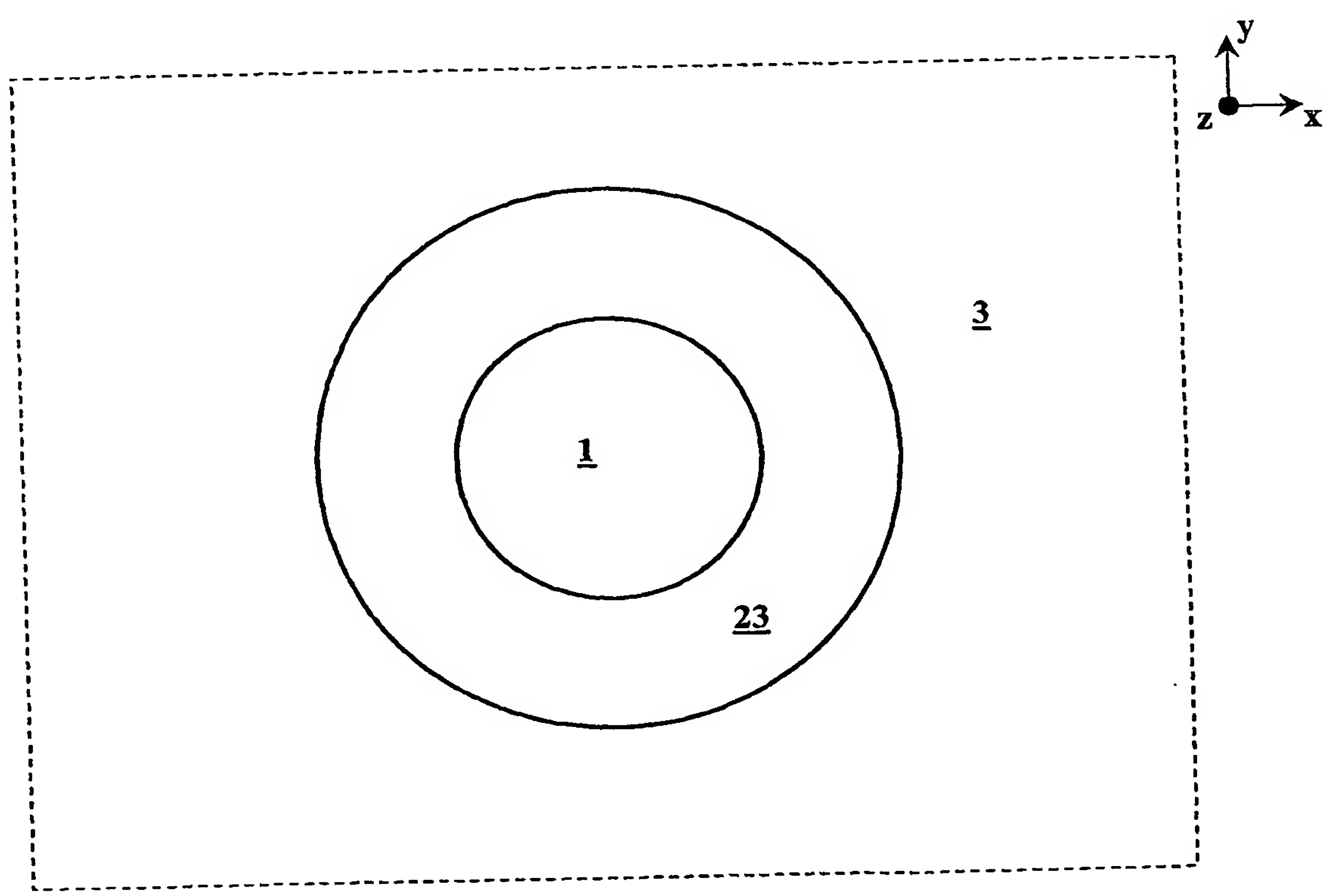


FIGURE 9

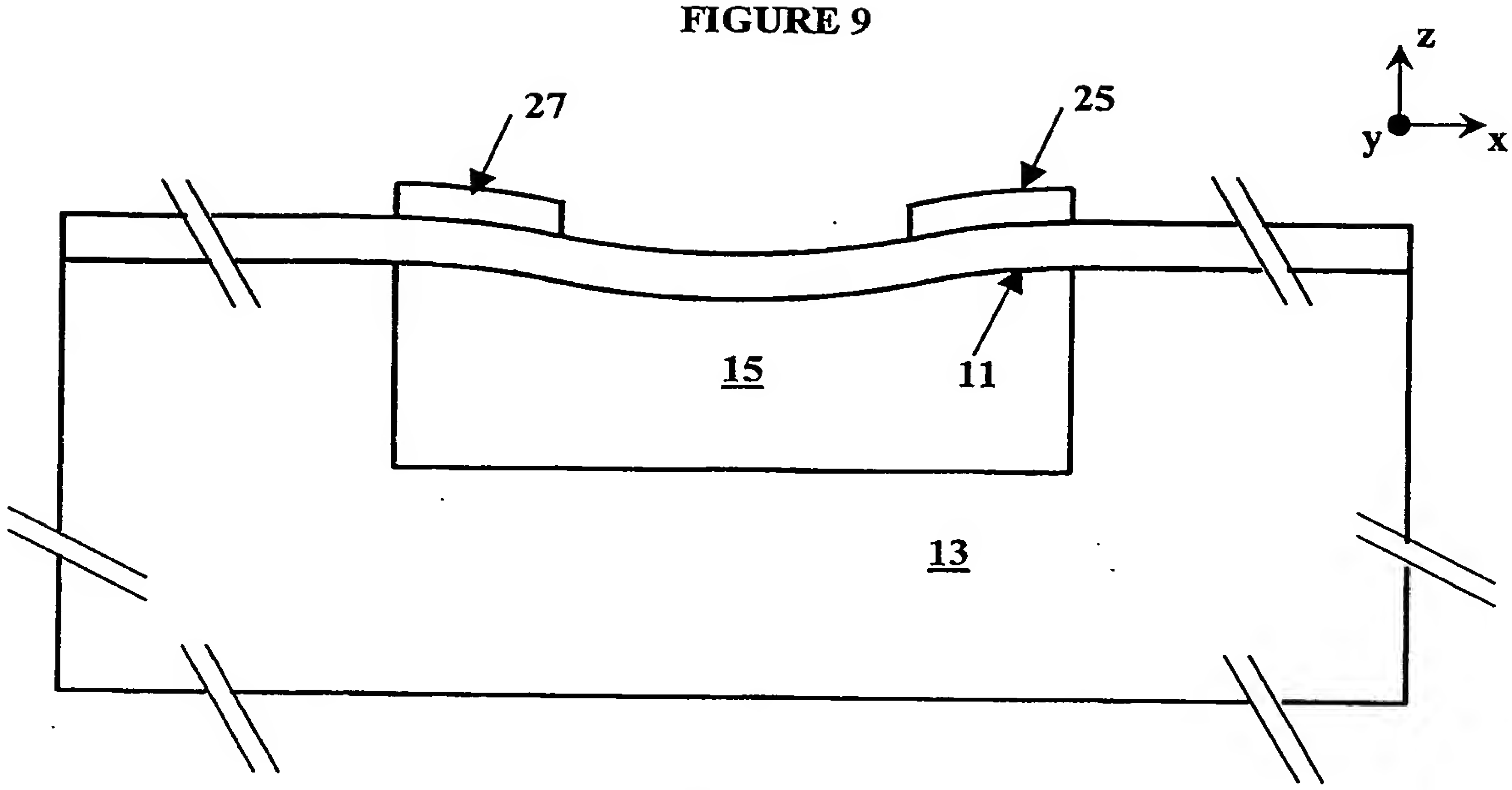


FIGURE 10

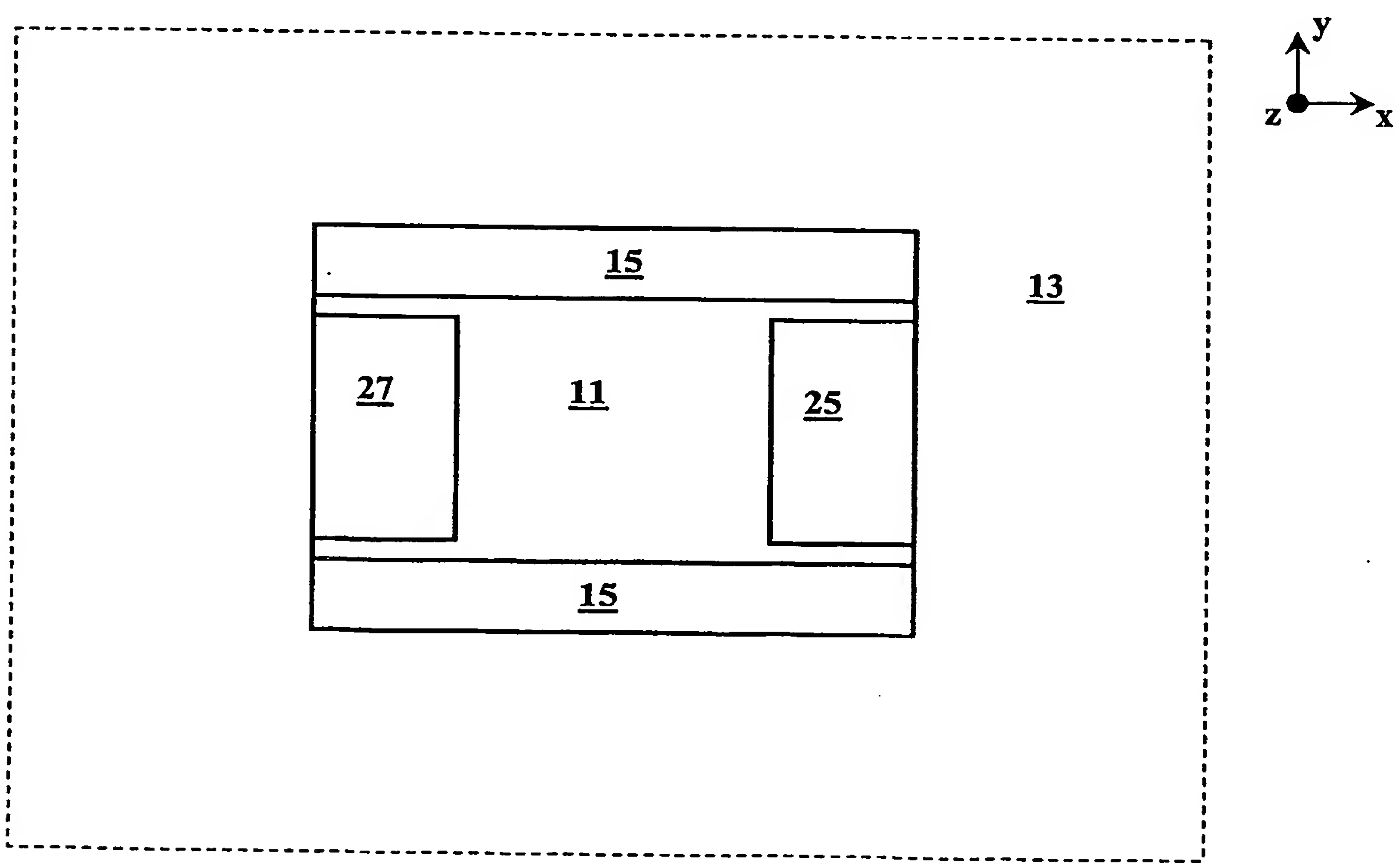


FIGURE 11

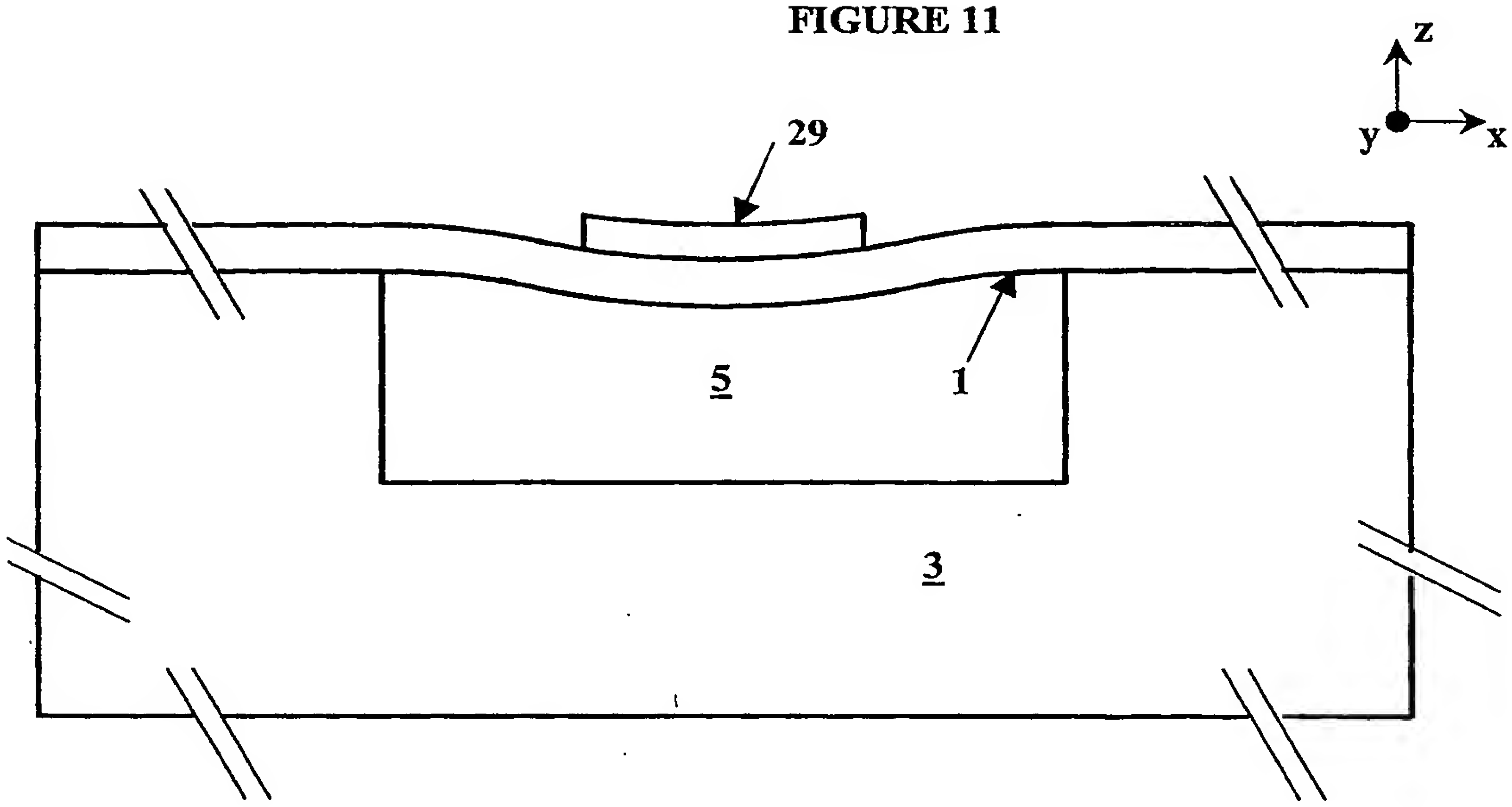


FIGURE 12

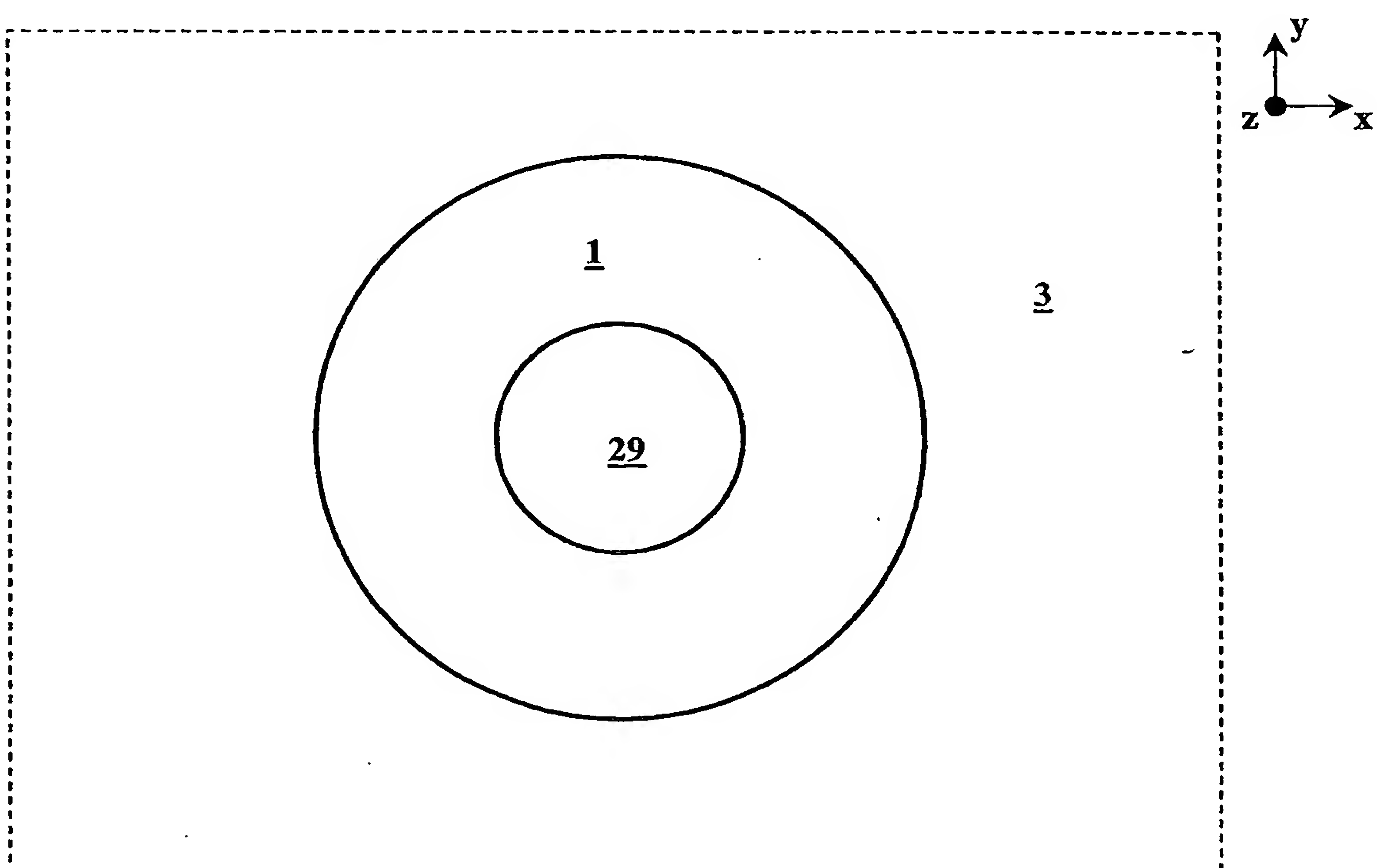


FIGURE 13

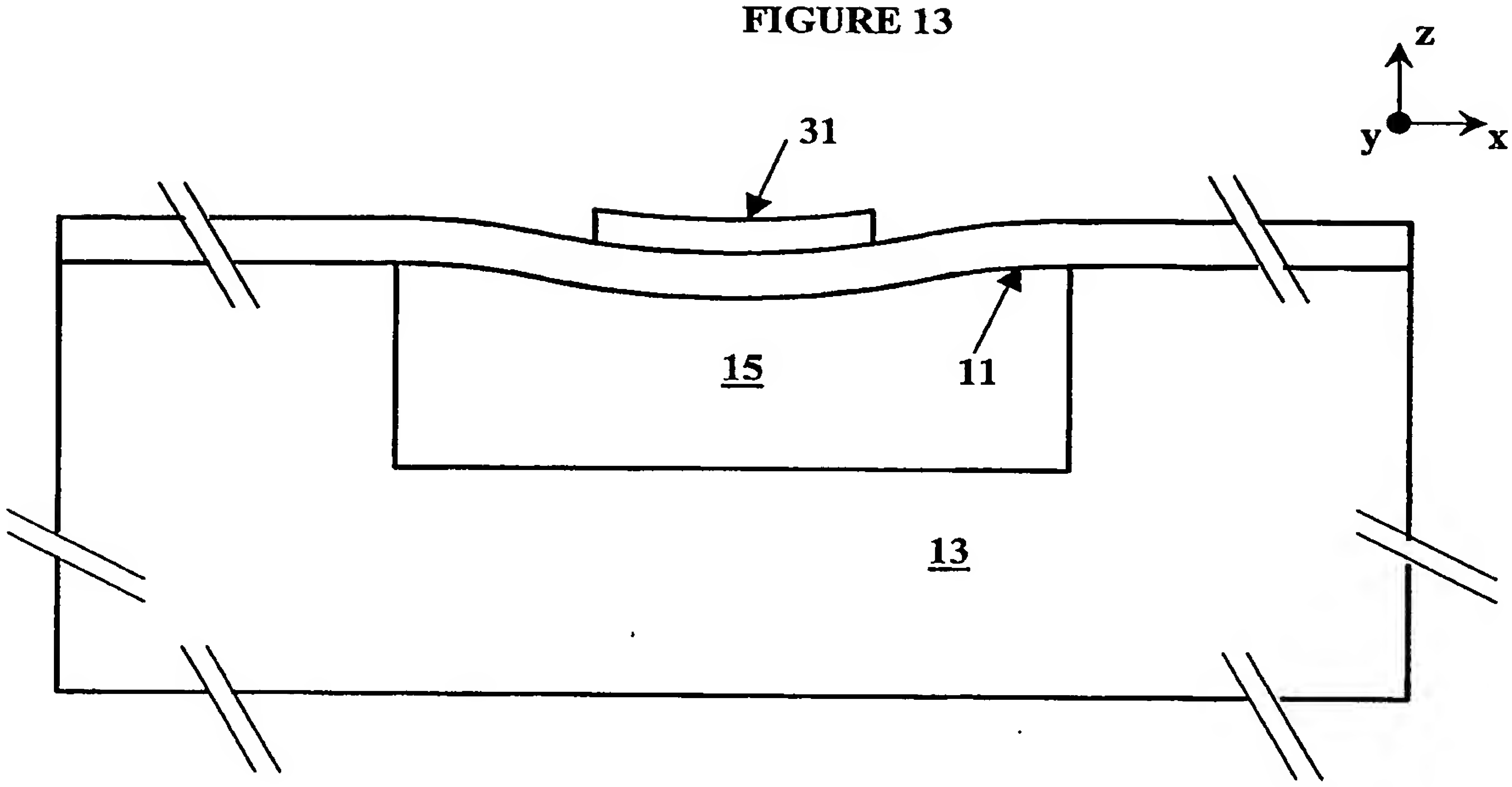


FIGURE 14

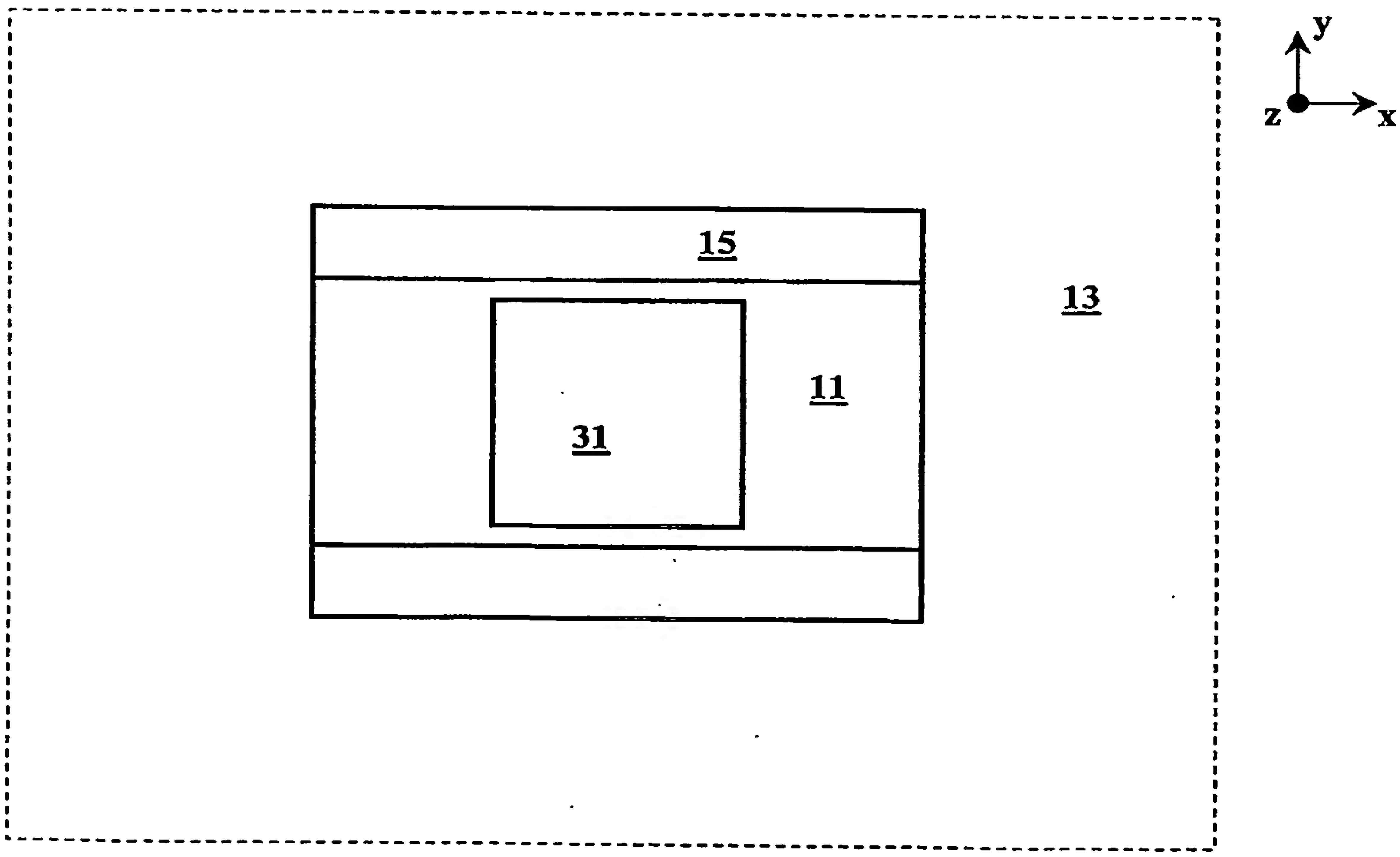


FIGURE 15

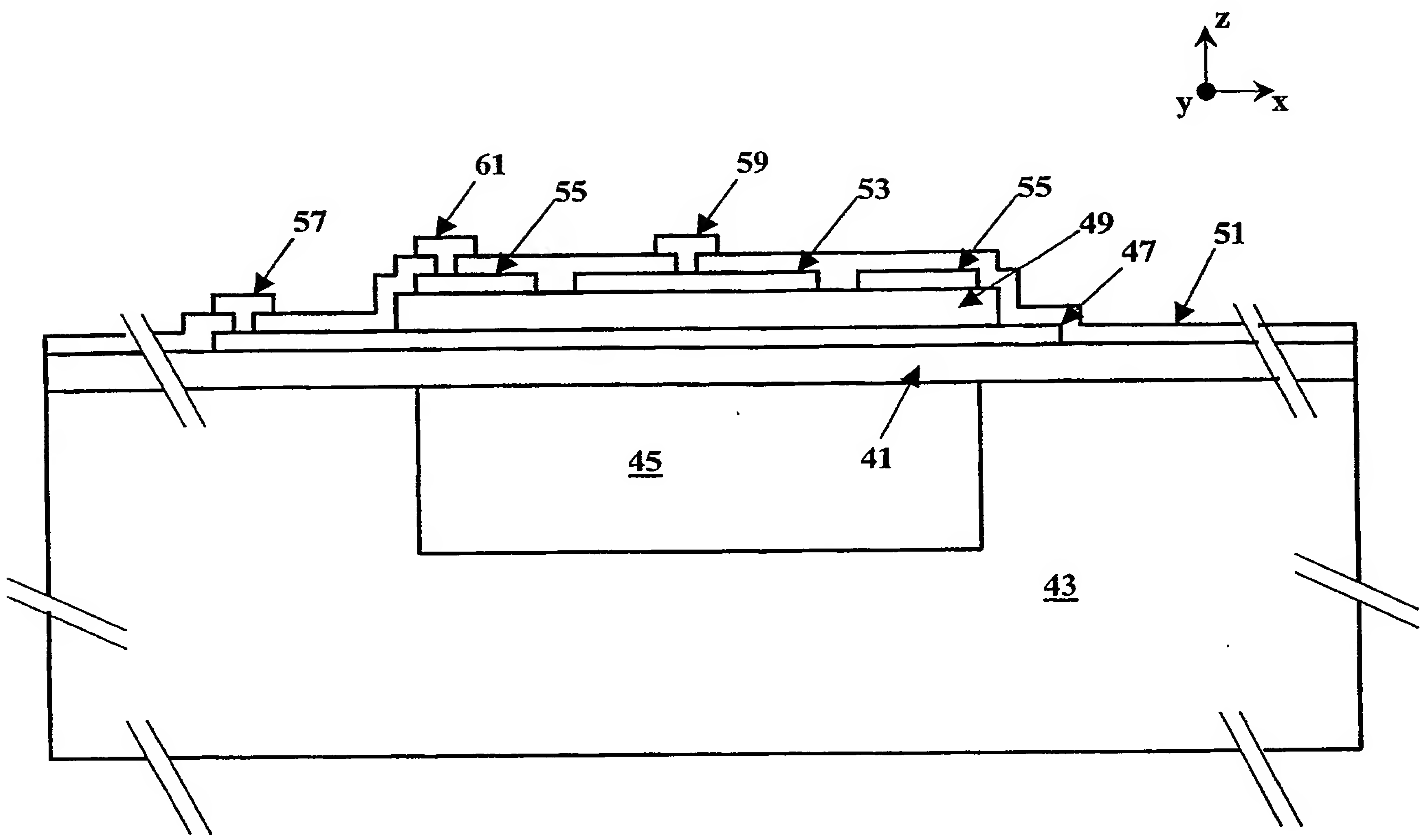


FIGURE 16

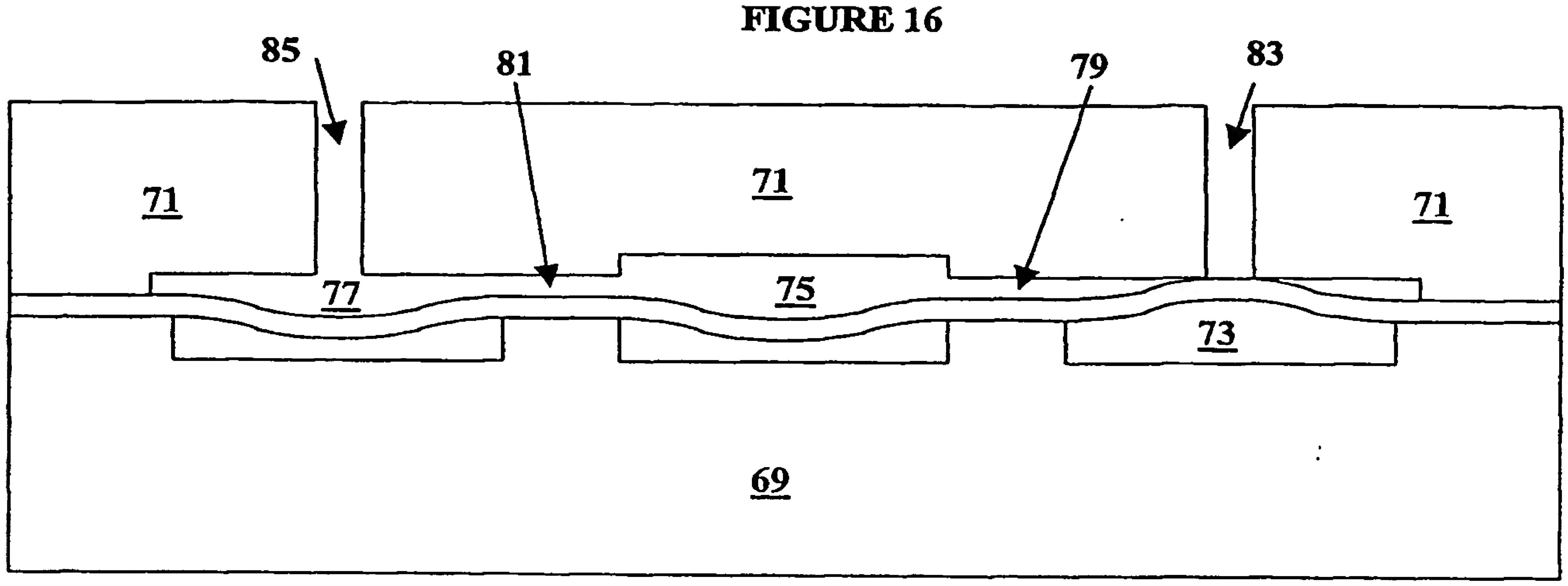


FIGURE 17

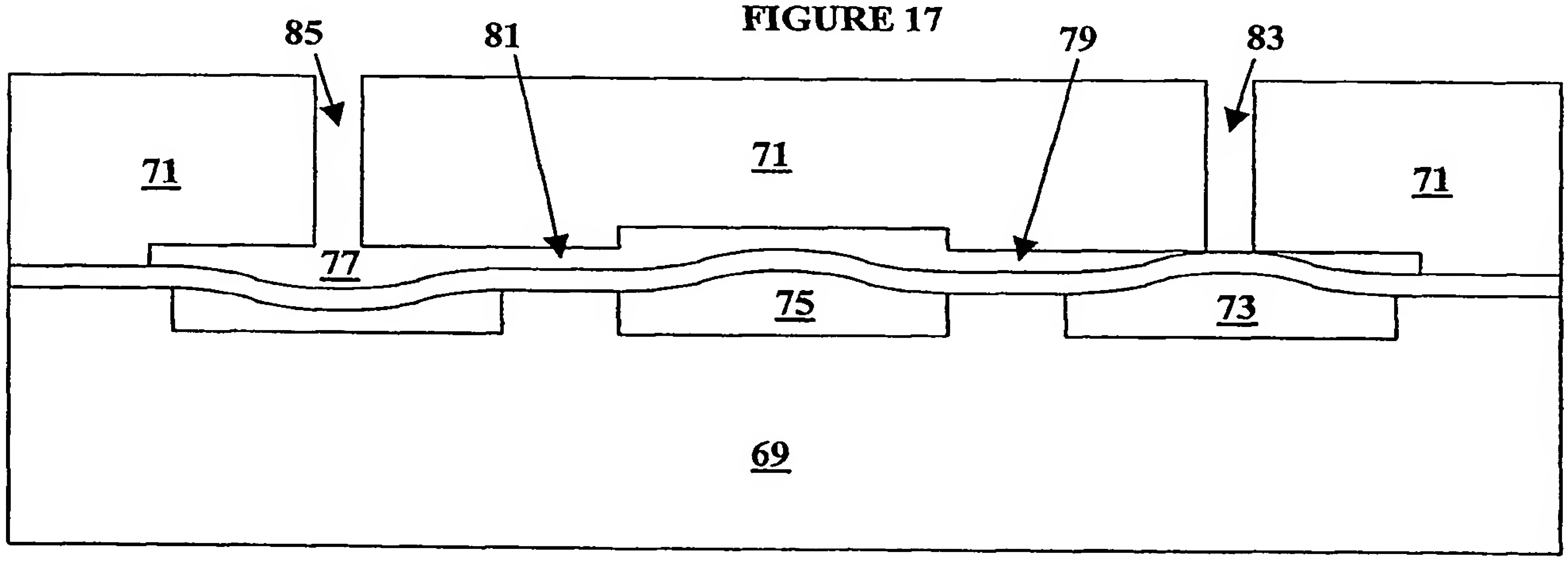


FIGURE 18

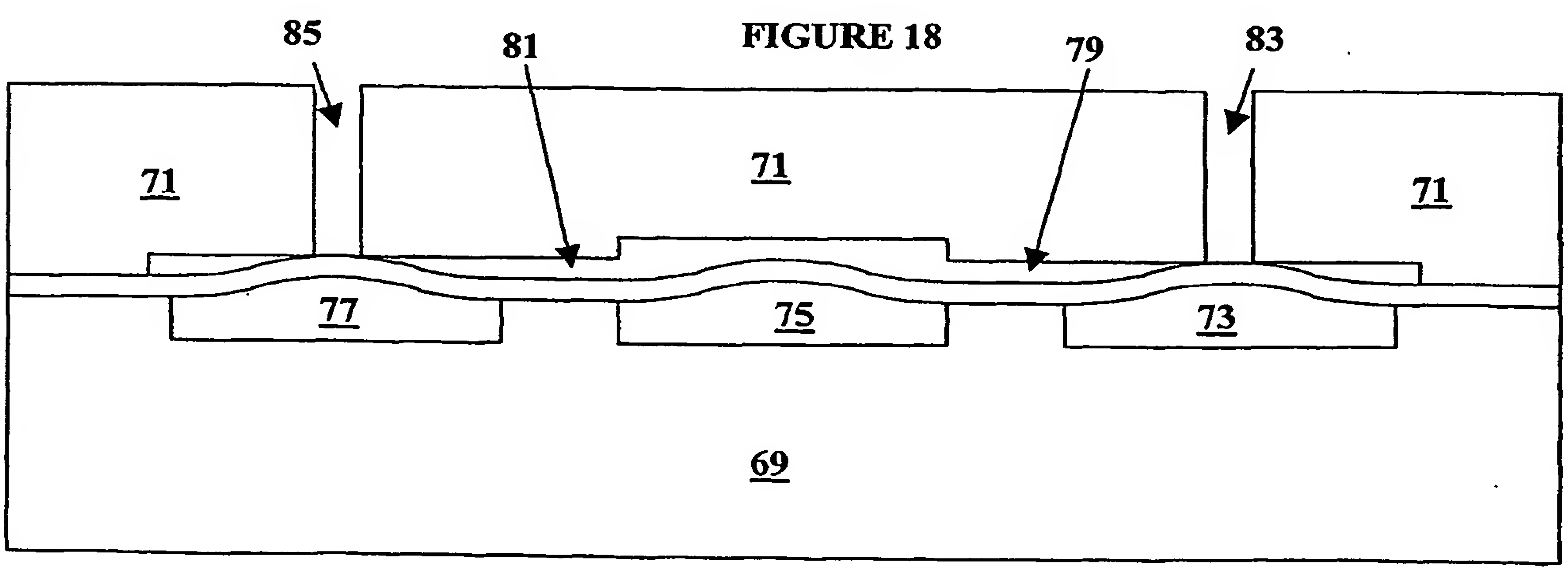


FIGURE 19

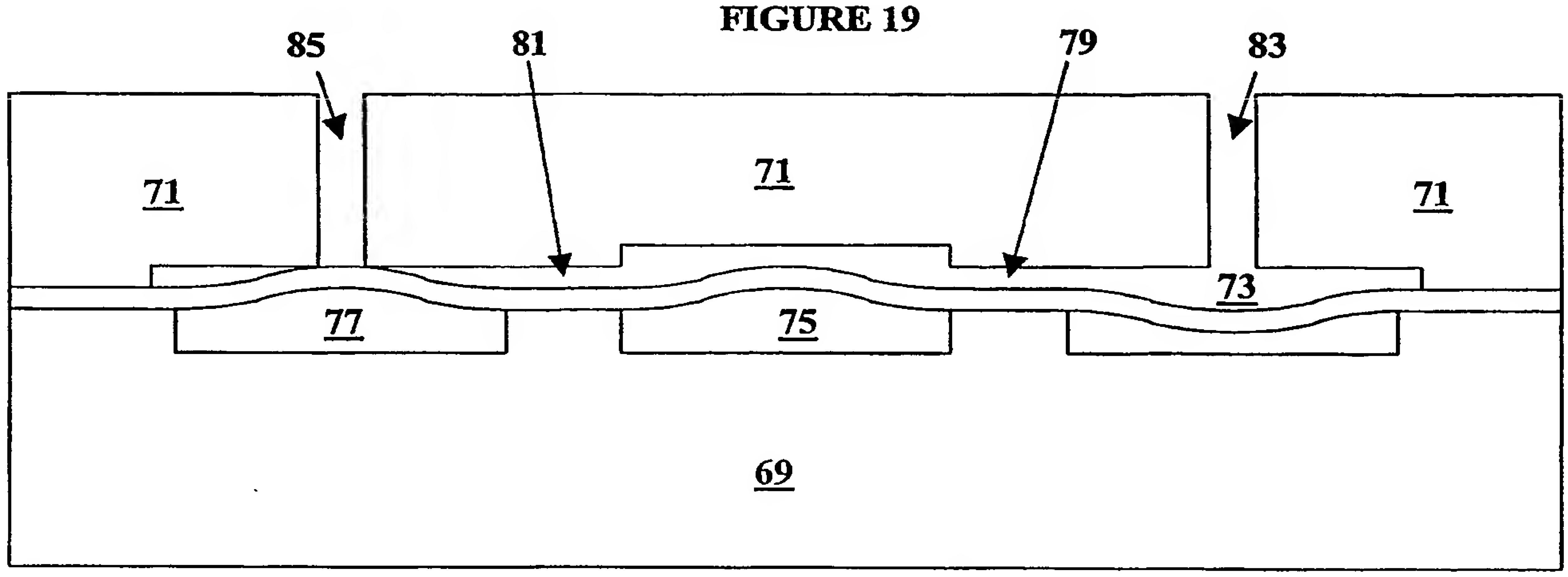


FIGURE 20

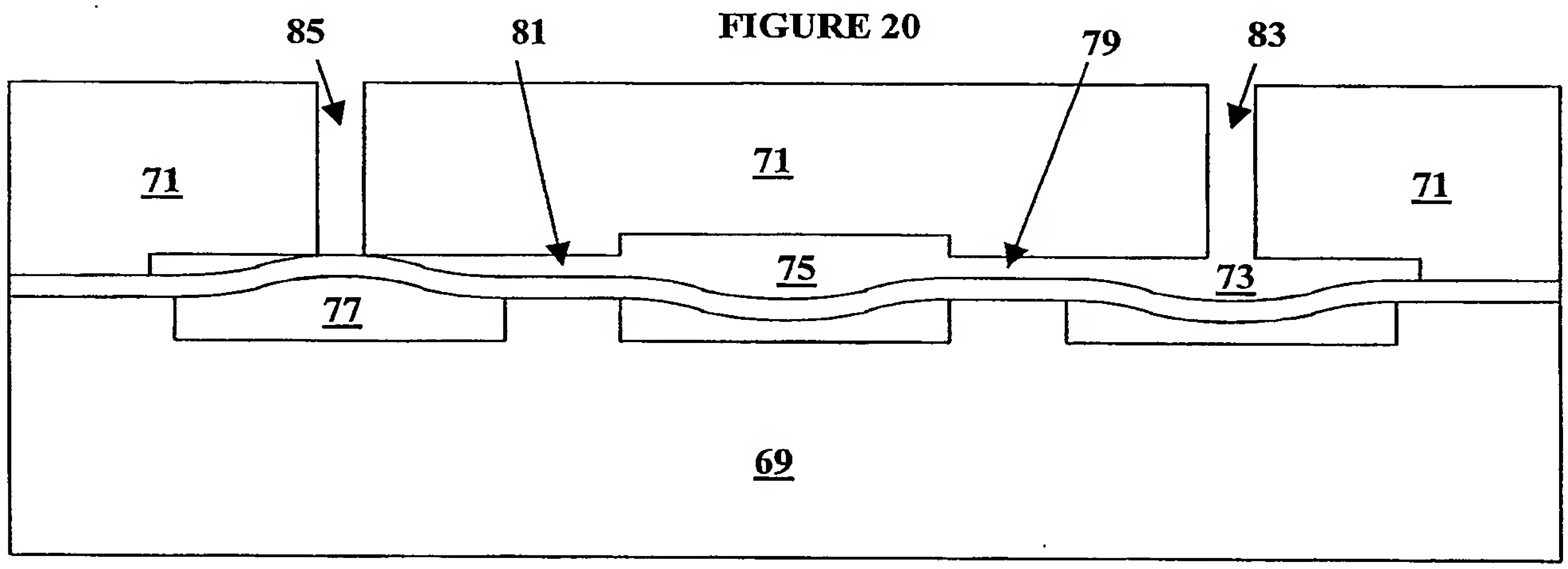


FIGURE 21

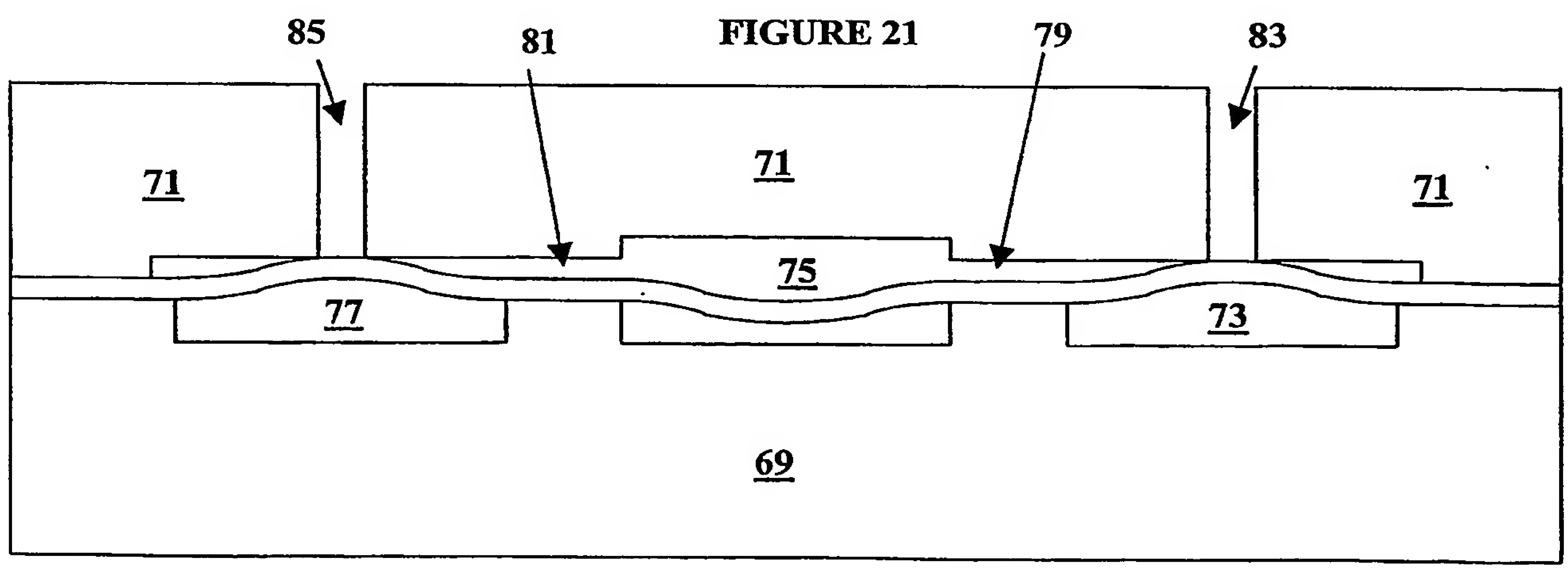


FIGURE 22

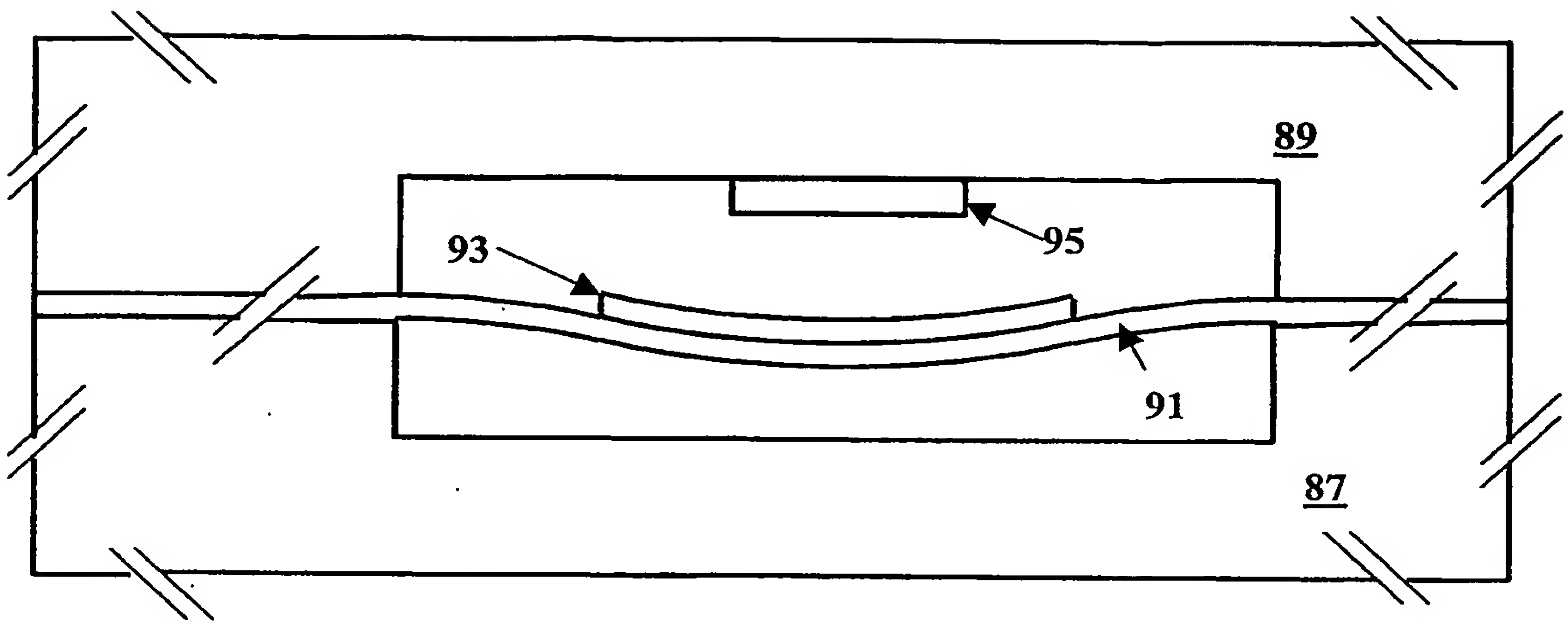


FIGURE 23

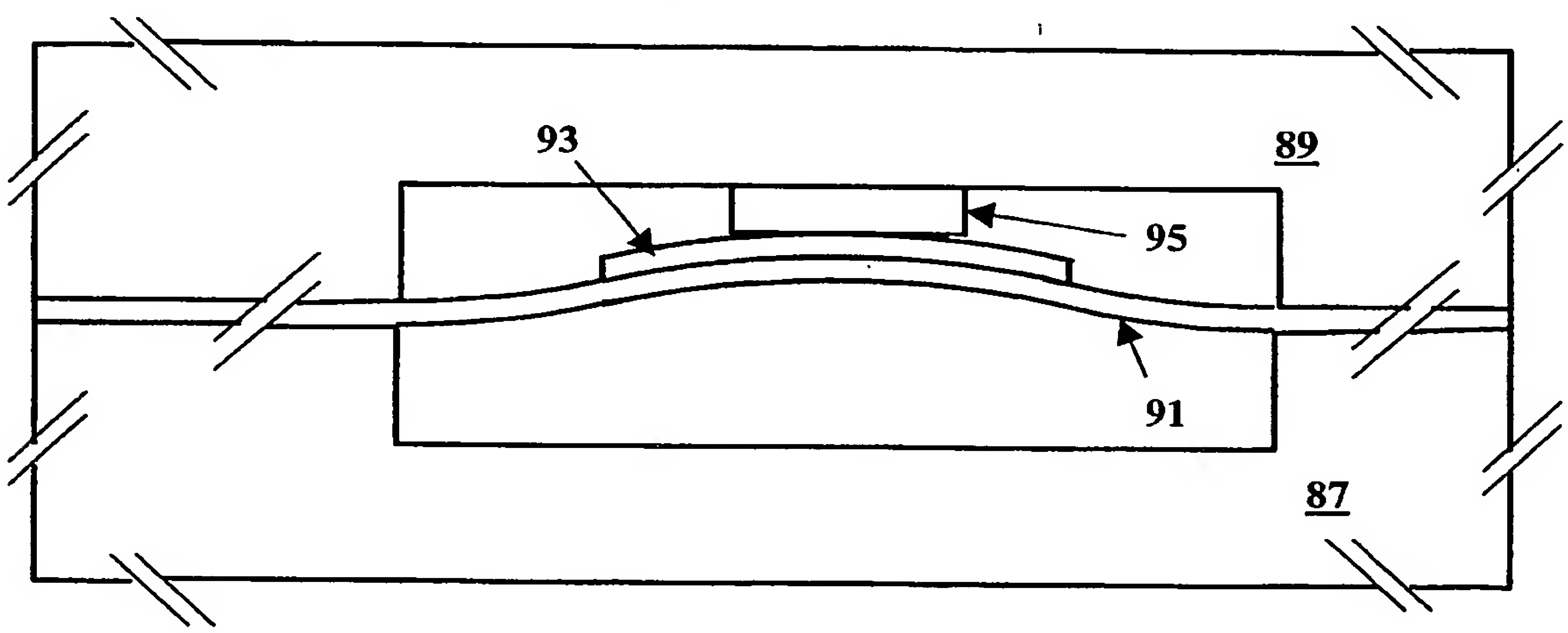


FIGURE 24

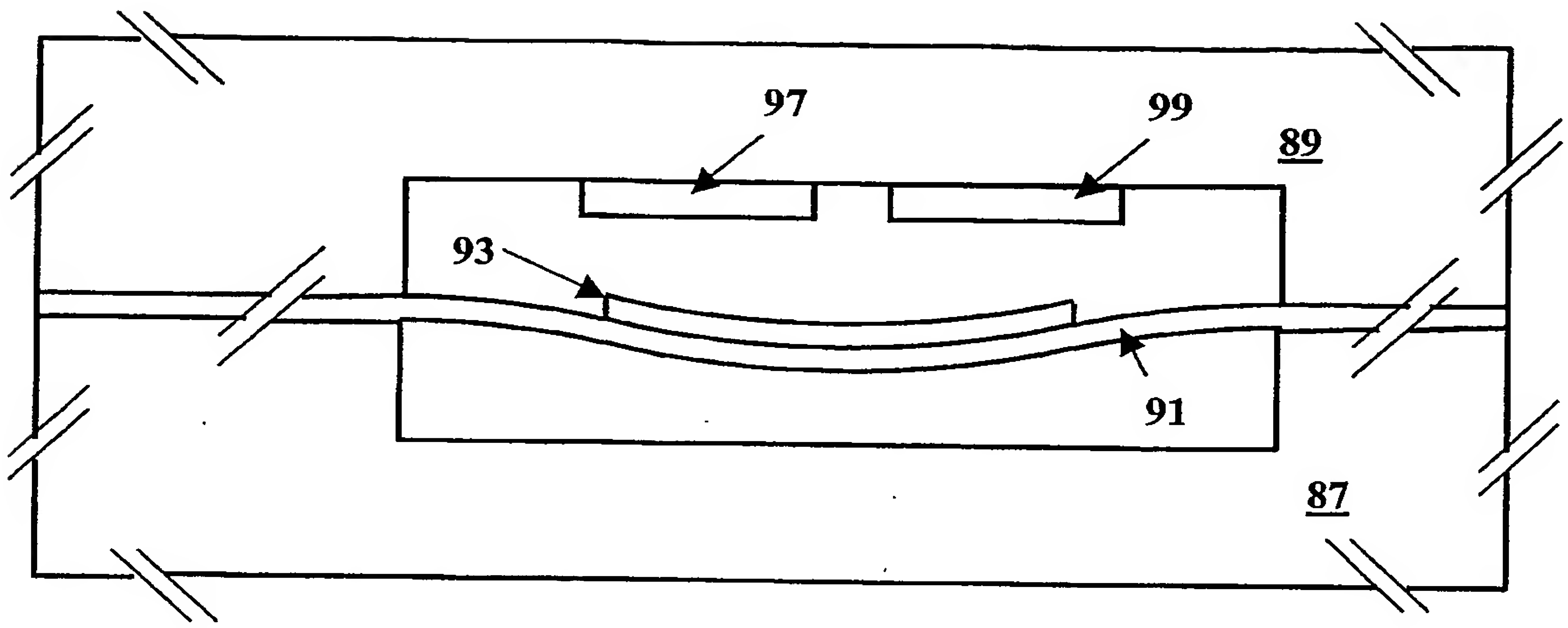
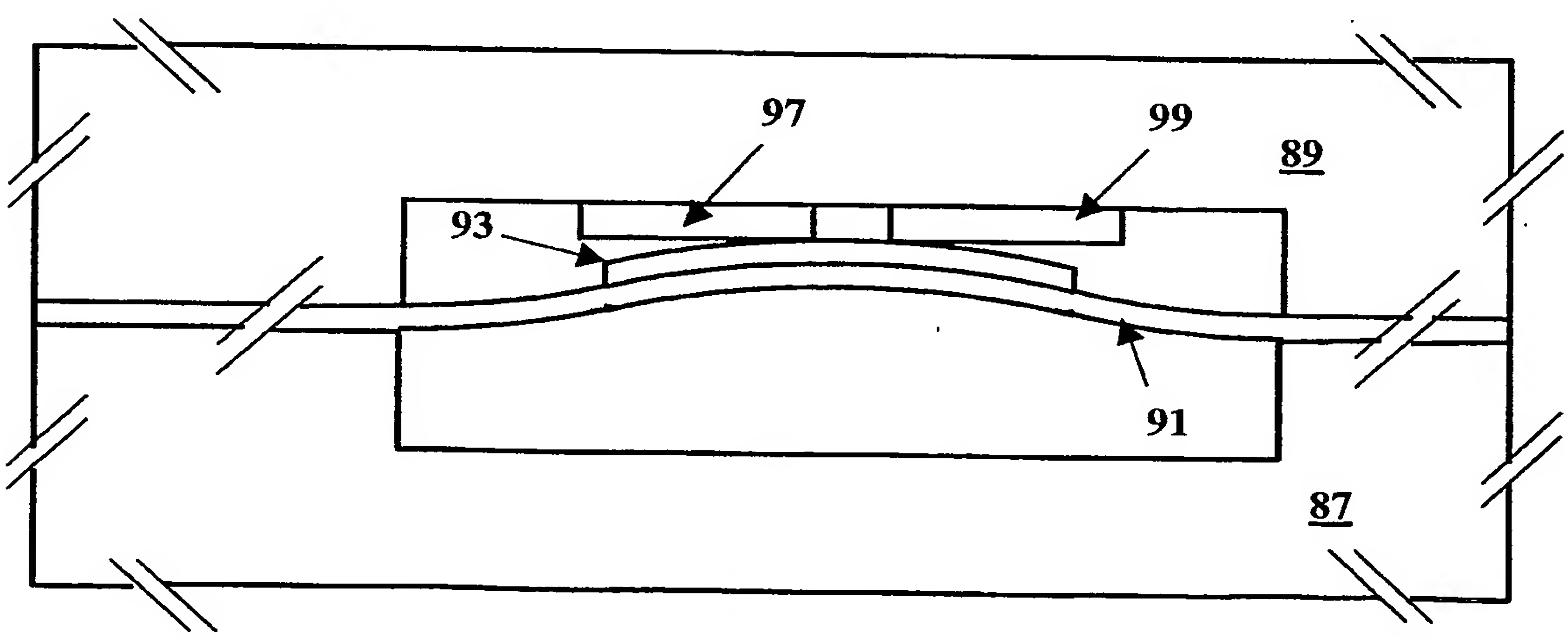


FIGURE 25



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 July 2004 (29.07.2004)

PCT

(10) International Publication Number
WO 2004/063090 A3

(51) **International Patent Classification**[7]: **H01L 41/09**, H01H 57/00, B81B 3/00, F04B 43/04, F16K 31/00

(21) **International Application Number:** PCT/US2004/000667

(22) **International Filing Date:** 12 January 2004 (12.01.2004)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
60/439,768 13 January 2003 (13.01.2003) US

(71) **Applicant** *(for all designated States except US)*: **TRIAD SENSORS INC.** [US/US]; 2700 Black Oaks Lane North, Minneapolis, MN 55447 (US).

(72) **Inventor; and**
(75) **Inventor/Applicant** *(for US only)*: **SCHILLER, Peter J.** [US/US]; 12370 Heather St. NW, Coon Rapids, MN 55433 (US).

(74) **Agents: XU, Min S. (Amy)** et al.; Dorsey & Whitney LLP, 50 South Sixth Street, Suite 1500, Minneapolis, MN 55402-1498 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

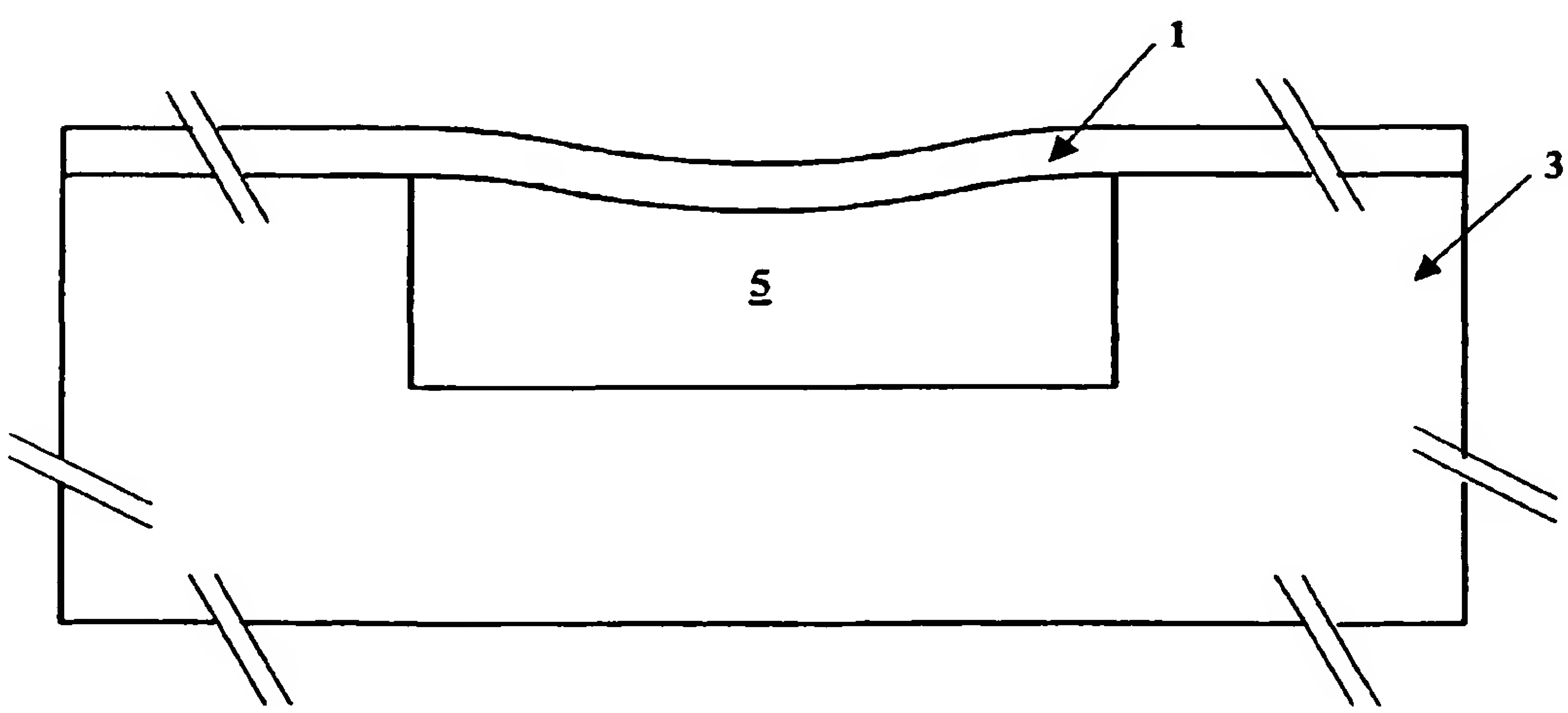
(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) **Date of publication of the international search report:** 23 December 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** HIGH DISPLACEMENT BISTABLE MICRO ACTUATOR



(57) **Abstract:** The present invention provides a bistable actuator device formed by thin films for generating mechanical motion in response to an electronic control signal. The present invention combines a thin film bistable mechanical member (1) under compressive stress with piezoelectric thin film force elements to generate improved force and displacement properties in the actuator device. Applications of the bistable actuator device include, but not limited to, a micro pump, and an electronic switch or relay.

WO 2004/063090 A3

INTERNATIONAL SEARCH REPORT

ational Application No
/US2004/000667

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L41/09 H01H57/00 B81B3/00 F04B43/04 F16K31/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L H01H B81B F04B F16K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO 03/014789 A (DRECHSLER UTE ; DESPONT MICHEL (CH); VETTIGER PETER (CH); WIDMER ROLAN) 20 February 2003 (2003-02-20) page 7, line 6 - page 8, line 5 page 9, line 30 - page 10, line 11 page 13, lines 1-25 figures 2,7,8	1-4, 11-13,15
X	FR 2 753 565 A (THOMSON CSF) 20 March 1998 (1998-03-20)	1-4,6,7, 10,11, 13,15
	page 3, line 22 - page 4, line 11 page 5, lines 19-30	
Y	page 7, line 26 - page 8, line 30; figures 2,3,5,6	8,9,12, 14,16,17

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2004	23/09/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Meul, H

INTERNATIONAL SEARCH REPORT

International Application No
/US2004/000667

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 383 195 A (KOLM ERIC A ET AL) 10 May 1983 (1983-05-10) column 3, line 42 - column 5, line 46 figures 1-3	1-5,11, 13,15 12,14,16
Y	SCHOMBURG W K ET AL: "Design optimization of bistable microdiaphragm valves" SENSORS AND ACTUATORS A, ELSEVIER SCIENCE S.A., LAUSANNE, CH, vol. 64, no. 3, 31 January 1998 (1998-01-31), pages 259-264, XP004116354 ISSN: 0924-4247 page 259, left-hand column, lines 1-20 figure 1	14
Y	EP 0 435 653 A (SEIKO EPSON CORP) 3 July 1991 (1991-07-03) page 6, line 39 - page 8, line 1 figures 1,2,5a,5b	16,17
Y	PATENT ABSTRACTS OF JAPAN vol. 2002, no. 02, 2 April 2002 (2002-04-02) -& JP 2001 277194 A (SUMITOMO METAL IND LTD), 9 October 2001 (2001-10-09) abstract paragraphs '0002!, '0003!	16
Y	EP 0 518 618 A (CANON KK) 16 December 1992 (1992-12-16) page 6, lines 2,3	8,9

INTERNATIONAL SEARCH REPORT

Information on patent family members

ıtional Application No
/US2004/000667

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 03014789	A	20-02-2003	EP	1456699	A2	15-09-2004
			WO	03014789	A2	20-02-2003
FR 2753565	A	20-03-1998	FR	2753565	A1	20-03-1998
			EP	0861496	A1	02-09-1998
			WO	9811586	A1	19-03-1998
			JP	2000502496	T	29-02-2000
US 4383195	A	10-05-1983	NONE			
EP 0435653	A	03-07-1991	JP	3217672	A	25-09-1991
			JP	3225085	A	04-10-1991
			JP	3225086	A	04-10-1991
			JP	3225089	A	04-10-1991
			JP	3233177	A	17-10-1991
			JP	3199682	A	30-08-1991
			CN	1053664	A	07-08-1991
			DE	69118216	D1	02-05-1996
			DE	69118216	T2	14-11-1996
			EP	0435653	A1	03-07-1991
			EP	0439327	A1	31-07-1991
			US	5157699	A	20-10-1992
			US	5248904	A	28-09-1993
			DE	69009431	D1	07-07-1994
			DE	69009431	T2	15-09-1994
			HK	103397	A	15-08-1997
			US	5171132	A	15-12-1992
			CN	1054119	A	28-08-1991
JP 2001277194	A	09-10-2001	NONE			
EP 0518618	A	16-12-1992	JP	2923813	B2	26-07-1999
			JP	4364413	A	16-12-1992
			AT	170628	T	15-09-1998
			CA	2070946	A1	12-12-1992
			DE	69226817	D1	08-10-1998
			DE	69226817	T2	21-01-1999
			EP	0518618	A2	16-12-1992
			US	5357108	A	18-10-1994